Soils Technical Report

MONTANA STATEWIDE OIL AND GAS ENVIRONMENTAL IMPACT STATEMENT AND AMENDMENT OF THE POWDER RIVER AND BILLINGS RESOURCE MANAGEMENT PLANS

Prepared for:

U.S. DEPARTMENT OF INTERIOR
BUREAU OF LAND MANAGEMENT
MILES CITY FIELD OFFICE
111 Garryowen Road
Miles City, MT 59301

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This Technical Report has been prepared for the Bureau of Land Management (BLM) by ALL Consulting (Tulsa, Oklahoma) and subcontractor CH2M HILL (Boise, Idaho) in accordance with applicable contracting requirements specific to ALL Consulting's Purchase Order with the BLM and General Services Administration (GSA) contract for Environmental Advisory Services.

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ACRONYMS

ac-ft/day	acre-feet per day
ALL	ALL Consulting
BLM	Bureau of Land Management
CBM	Coalbed Methane
cfs	cubic feet per second
dS/m	deciSiemens per meter
EC	Electrical Conductivity
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
gpm	gallons per minute
GSA	General Services Administration
MBOGC	Montana Board of Oil and Gas Conservation
mcf/day	million cubic feet per day
MDEQ	Montana Department of Environmental Quality
mg/L	milligrams per liter
mmhos/cm	millihos per centimeter
MPDES	Montana Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
NEPA	National Environmental Policy Act
PRB	Powder River Basin
RFD	Reasonable Foreseeable Development
RMA	Resource Management Area
RMP	Resource Management Plan
SAR	Sodium Adsorption Ratio
STATSGO	State Soil Geographic Database
TDS	Total Dissolved Solids
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WSAL	Wildlife Spatial Analysis Lab

CHAPTER 1: INTRODUCTION

The goal of the Soils Technical Report is to present the potential impacts from the coalbed methane (CBM) extraction process on land and the environment. This report pertains to options for water disposal or reuse that might affect land. The main focus is on impacts to agriculture, including potential effects on crops, livestock, and soils. The predominant land use in the project area is for agriculture, with ranching being the main agricultural use of the land.

1.1 BACKGROUND

Coalbed methane is a carbon-based gas that occurs naturally in large quantities in the seams in unmined coalbeds. The CBM is typically contained within the micropores of the coal and is retained in place by the pressure created by the presence of water. During production, this water is pumped to the ground surface to lower the pressure in the coalbed reservoir and to stimulate the release of methane from the coal.

Methane from unmined coalbeds has been produced on a minor scale since the early 1900s when a rancher in the Powder River Basin (Wyoming) drilled a water well into a coalbed and started heating the buildings with the produced gas. Until the 1980s, coal seams generally were not considered to be a reservoir target, even though producers often drilled through coal seams when going to deeper horizons.

The Powder River Basin in Montana and Wyoming is one of the most active new areas of CBM production. Currently more than 3,000 producing wells are in the Wyoming portion of the Basin and the U.S. Bureau of Land Management (BLM) in Wyoming is preparing to estimate the impact of as many as 30,000 CBM wells (Regele and Stark 2000). CBM production is currently greater than 333,000 million cubic feet per day (mcf/day) and the accompanying water production is more than 1.28 million barrels per day (124 ac-ft/day).

CBM gas production is already underway in Montana and development similar to that in Wyoming appears likely. The Montana Board of Oil and Gas Conservation (MBOGC) has issued about 290 permits to drill CBM wells in the state with about 120 wells having been drilled on non-Federal lands near Decker (Regele and Stark 2000). All of the water that is discharged by these wells flows toward or directly into the Tongue River and its tributaries. The Tongue River and the Powder River in Montana are two drainage areas that are of immediate interest for CBM development.

As the number of CBM wells increases, the amount of water produced will also increase. Although water production from a CBM well typically declines over the life of the well, the decline in water production in the basin as a whole is not expected to occur until most of the CBM wells have been developed and produced for a number of years. One of the alternatives to river discharge is discharge or reuse onto land. This will be the main subject of this report.

1.2 REGULATORY RESPONSIBILITIES

The landspreading of CBM water, because of its source and quality, comes under the jurisdiction of the Montana Department of Environmental Quality (MDEQ). The governor of Montana recently directed Montana agencies, with MDEQ and MBOGC as the lead agencies, to carry out a review of anticipated CBM activity (Regele and Stark 2000). Any environmental document produced by the review will delineate the CBM-related responsibilities of each agency and the resources that CBM development affects. While specific regulatory requirements for the use of CBM water are not addressed in this Technical Report, it should be understood that any suggested use of CBM water would have to satisfy the requirements of the Montana Environmental Policy Act and any specific requirements of MDEQ.

1.3 STUDY AREA FOCUS

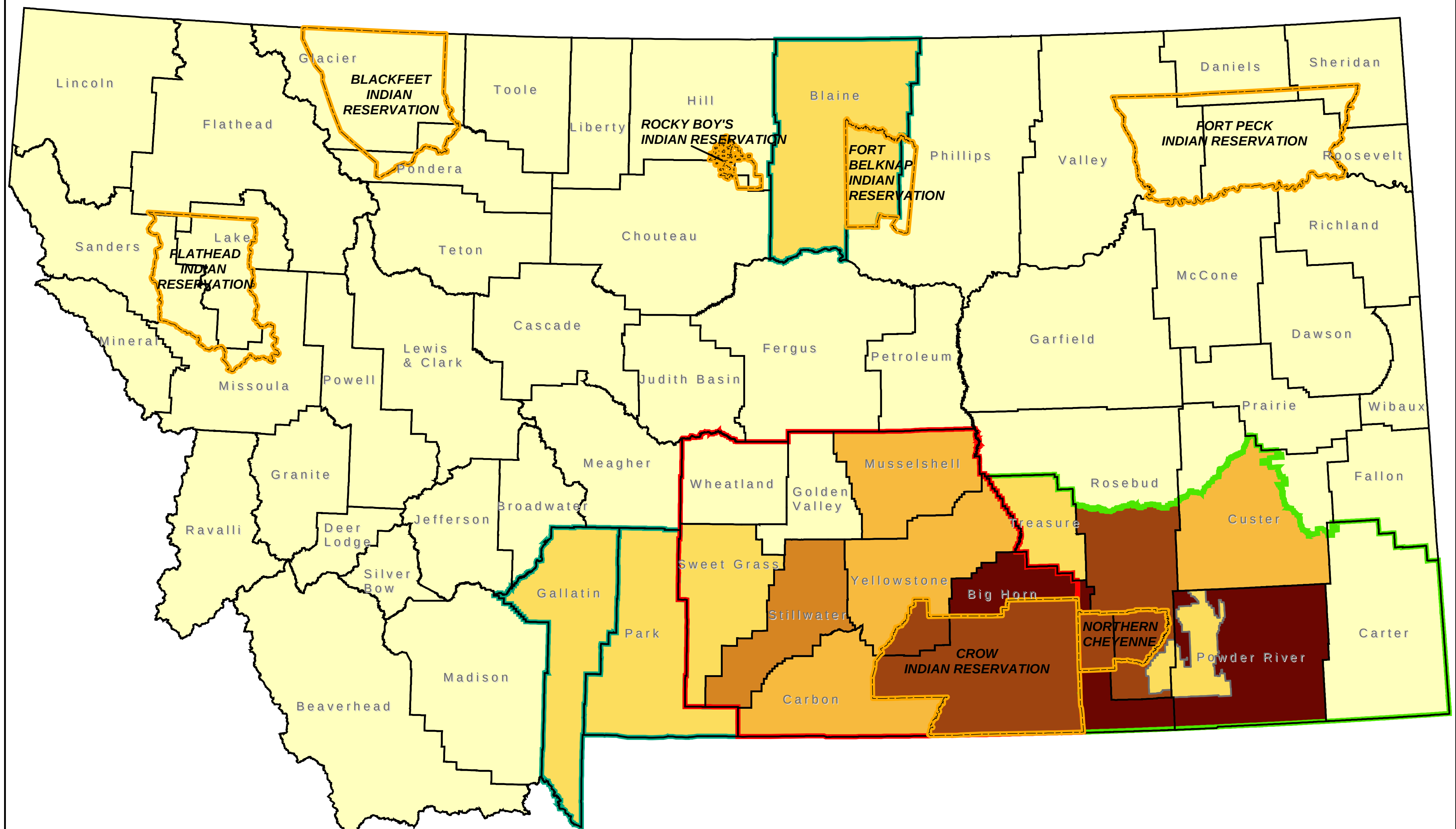
This Technical Report is an appendage to the Montana Statewide Oil and Gas Environmental Impact Statement (EIS) and Amendment of the Powder River and Billings Resource Management Plans (RMPs) to be released in 2001. The EIS covers the state of Montana, with an emphasis on the BLM's Powder River Resource Management Area (RMA), Billings RMA, and three isolated areas in Blaine, Park, and Gallatin counties (Exhibit 1). In the Reasonable Foreseeable Development (RFD) for Montana, the BLM estimates the potential CBM wells statewide in the next 20 years to be from 10,000 to 26,000 wells (BLM 2001). As shown in Exhibit 1, the Powder River and Billings RMAs represent the bulk of the potential CBM development in Montana with a minimal number of wells being predicted in the other three counties. Because of the concentration in these two areas, this Technical Report will focus only on the Powder River and Billings RMAs. Conclusions for other areas of the State can be inferred from this study.

1.4 PURPOSE

From previous studies, it is known that CBM water is typically of lower quality than surface water or other groundwater. Because of this, the use of CBM water for irrigation or other agricultural uses may result in some degree of negative impacts to the soils and the crops grown in the soils. These impacts may have to be mitigated if CBM water is to be used in area agriculture for irrigation, livestock, and other uses.

This Technical Report presents a general characterization of CBM water, discusses the potential for use of the water in agriculture, suggests the potential impacts of its use or disposal on land, and presents an analysis of the findings.

Exhibit 1: RFD CBM Development



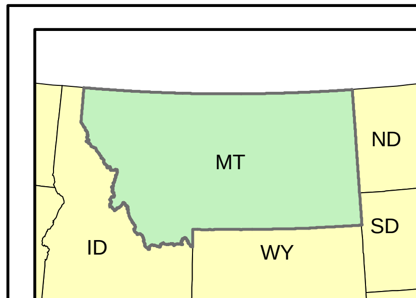
Legend

- Billings RMP Area
- Powder River RMP Area
- Special Consideration Counties
- Native American Reservations

Number of CBM Wells

- 0
- 1 - 100
- 101 - 400
- 401 - 700
- 701 - 4,000
- 4,001 - 7,000

This map shows the maximum number of CBM wells as described in the Reasonable Foreseeable Development Scenario. NOTE: The majority of development for Big Horn county will be located in the southern portion.



Location Map

Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

1:3,000,000

DATA SOURCES:

Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Development Data: BLM Reasonable Foreseeable Development Scenario

CHAPTER 2: CBM WATER, SOILS, AND CROP CHARACTERIZATION

When considering the impacts of CBM water, it is necessary to characterize the water itself, the soils on which the water will be applied, and the crops on which the water may be used.

2.1 CBM WATER

A knowledge of the quality of CBM water is necessary to define the potential impacts of its use and determine its suitability for the irrigation of crops. Rice, et al (2000) developed extensive quality characteristics of CBM water from 47 CBM wells in the Powder River Basin (PRB) in Wyoming. Bauder (1999) also compiled CBM water quality characteristics for 19 wells near Decker, Montana, also in the PRB, and compared the data to that of the Tongue River. For the purposes of this Technical Report, these data are considered representative of the overall PRB and will be used to evaluate the use of CBM water in the Montana portion of the PRB. However, it is important to understand that the quality of CBM water will vary by location in the PRB. Site-specific water quality information should be developed when analyzing impacts for specific use locations.

The high, low, median and mean concentrations of selected constituents in the CBM water from the 47 Wyoming wells are shown in Exhibit 2. The characteristics shown in Exhibit 2 show that a wide variance in quality occurs among the 47 wells, indicating the importance of knowing the quality of the water produced from a specific well or wells that will be used to provide irrigation water to a specific site.

The average constituent concentrations of the 19 Decker wells and surface water from the Tongue River are presented in Exhibit 3. The significant comparisons from these data include the following: Total Dissolved Solids (TDS) averaged four times greater than the Tongue River; Sodium Adsorption Ratio (SAR) averaged 30 to 50 times greater; sodium averaged 15 to 20 times greater; electrical conductivity (EC), chlorides, alkalinity, and bicarbonate averages were only slightly (4 to 5 times) greater; and sulfates and magnesium averages had no significant changes from that of the Tongue River. A comparison of the CBM water data from Exhibits 2 and 3 shows differences in some constituents (mainly, EC, SAR, sodium, and sulfate), which emphasizes the importance of using site-specific data in future impact analyses.

2.2 SOILS

A general soil association map for Montana has been published in a digital format by the U.S. Department of Agriculture's (USDA's) Natural Resources Conservation Services (NRCS). The State Soil Geographic Database (STATSGO) (USDA NRCS 1996) provides a general overview of soils distribution and occurrences in the planning area, and is not suitable for site-specific evaluations. General soils information presented in the STATSGO database is presented in Appendix A. Exhibits include the areal extent, soil series characteristics, K-factor (erodibility factor), salinity, and SAR for the various soil groups in the Powder River and Billings RMAs.

EXHIBIT 2
CBM WATER CHARACTERISTICS

Characteristic	Lowest Conc.	Mean Conc.	Median Conc.	Highest Conc.
	(mg/L, except as noted)			
pH, units	6.8	7.3	7.3	7.6
EC, dS/M	0.47	1.30	1.13	3.02
Chloride	5.2	13	9.95	64
Sulfate	<0.1	2.4	0.81	8.6
Ammonia	1.1	2.4	2.3	4.8
Calcium	9.1	32	32	69
Floride	0.42	0.92	0.895	1.7
Potassium	3.8	8.4	7.6	18
Magnesium	1.6	16	16	46
Sodium	110	300	245	800
SAR, units	5.7	12	8.3	32
Iron	0.03	0.8	0.55	4.9
Aluminum	<0.05	<0.05	<0.05	<0.05
Arsenic	<0.0002	<0.0004	<0.000235	0.0026
Boron	<0.1	<0.107	<0.1	0.217
Beryllium	<0.0001	<0.0001	<0.0001	<0.0001
Cadmium	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt	<0.0001	<0.00011	<0.0001	0.00024
Chromium	<0.0001	<0.00098	<0.0001	0.0012
Copper	0.0015	0.00537	0.0041	0.00286
Mercury	<0.000005	<0.00007	<0.0001	0.00025
Lithium	0.018	0.0583	0.047	0.208
Manganese	0.0018	0.0329	0.023	0.101
Nickel	0.0005	0.0065	0.0047	0.0354
Lead	<0.0001	<0.00011	<0.0001	0.00043
Selenium	<0.002	<0.002	<0.002	<0.002
Vanadium	<0.0002	<0.0002	<0.0002	<0.0002
Zinc	<0.001	<0.00406	0.0015	0.0804

EXHIBIT 3
COMPARISON OF CBM AND TONGUE RIVER WATER QUALITY CHARACTERISTICS

Characteristic (mg/L, except as noted)	Average Tongue River	Average of 19 Discharge Wells	Change from Tongue River
pH, units	8.2	8.0	Non-Significant
EC, dS/m	0.64	2.39	Increase 4x
TDS	439	1580	Increase 4x
SAR, units	0.79	34.8	Increase 40x
Chloride	3	17.5	Increase 5x
Alkalinity	192	1110	Increase 5x
Bicarbonate	226	1335	Increase 5x
Magnesium	38	25	Non-Significant
Sulfate	174	250	Increase 1.5x
Sodium	32	574	Increase 18x

Source: Bauder 1999

The layout of the soils in the study area is shown and described in Exhibits A-1 through A-3 in Appendix A for the Billings RMA, and Exhibits A-4 through A-6 for the Powder River RMA. The soils generally range from loams to clays, but are principally loams to silty clay loams.

Slope and K-factor are values that are used in the estimation of soil erosion potential. Slope values range up to greater than 40 percent; however, many soils have slopes of zero to about 10 percent that are likely irrigable. Exhibits A-7 and A-8 in Appendix A present the mean K-factor of the soils in the Billings and Powder River RMAs, respectively. The K-factor is a measure of the susceptibility of the soil to erosion by water. Soils having the highest K-factor values (range is from 0.10 to 0.64) are the most erodible. Almost all of the soils have low K-factors (below 0.37). Easily eroded soils have a K-factor between 0.37 and 0.7, and resistant soils have a K-factor less than 0.37 (Jarrett 1995).

Exhibits A-9 and A-10 in Appendix A present the mean of the high range of salinity of the soils in the Billings and Powder River RMAs, respectively. (Note: STATSGO provides a range of low and high values for salinity for soils. The mean of the high value of the range was used to be conservative). Exhibits A-3 and A-6 present the salinity ranges in tabular format. Most of the soils are low in salinity and, with few exceptions, are low in sodium. Exhibit A-11 in Appendix A shows the maximum SAR values for all of the soil mapping units for Montana. The SAR values in the study areas and statewide vary widely, and should be evaluated on a site-specific basis in further studies.

Based on the generally fine texture of the surface soils (clayey), much of the soil will likely be susceptible to increasing sodicity when irrigated with water having a high SAR. Those soils with a coarser texture (sandy to loamy) and good internal drainage will be the least susceptible to increasing sodicity and salinity. Much of the soil is likely to be irrigable with good management. Actual irrigability of the soils, especially those on the higher terraces above the stream valleys, will have to be determined on a site-specific basis.

2.3 CROPS AND VEGETATION

The geographical location of the cropped areas in the study area, irrigated and non-irrigated, are shown in Exhibits 4 and 5—Agricultural Land Use Billings RMA and Agricultural Land Use Powder River RMA, respectively (WSAL 1998). Currently, virtually all of the irrigated lands are located in the river and stream valleys. Some dry farming occurs on the higher terraces above the valleys. Some of the land adjacent to the rivers and major tributaries is irrigated for wheat, feed grains, alfalfa, grass hay, sugar beets, and tame pasture (BLM 1992). However, the majority of the area is used for grazing livestock. One observation of Exhibit 5 for the Powder River Basin is there is very little irrigated land along the Tongue and Powder Rivers, which is where a majority of the potential CBM activity, based on the RFD, resides. It would most likely not be economically feasible to transport the CBM produced water long distances from the areas where it is produced to areas where crops are currently irrigated.

The principal irrigated crops grown in the study area and their estimated acreages are shown in Exhibit 6.

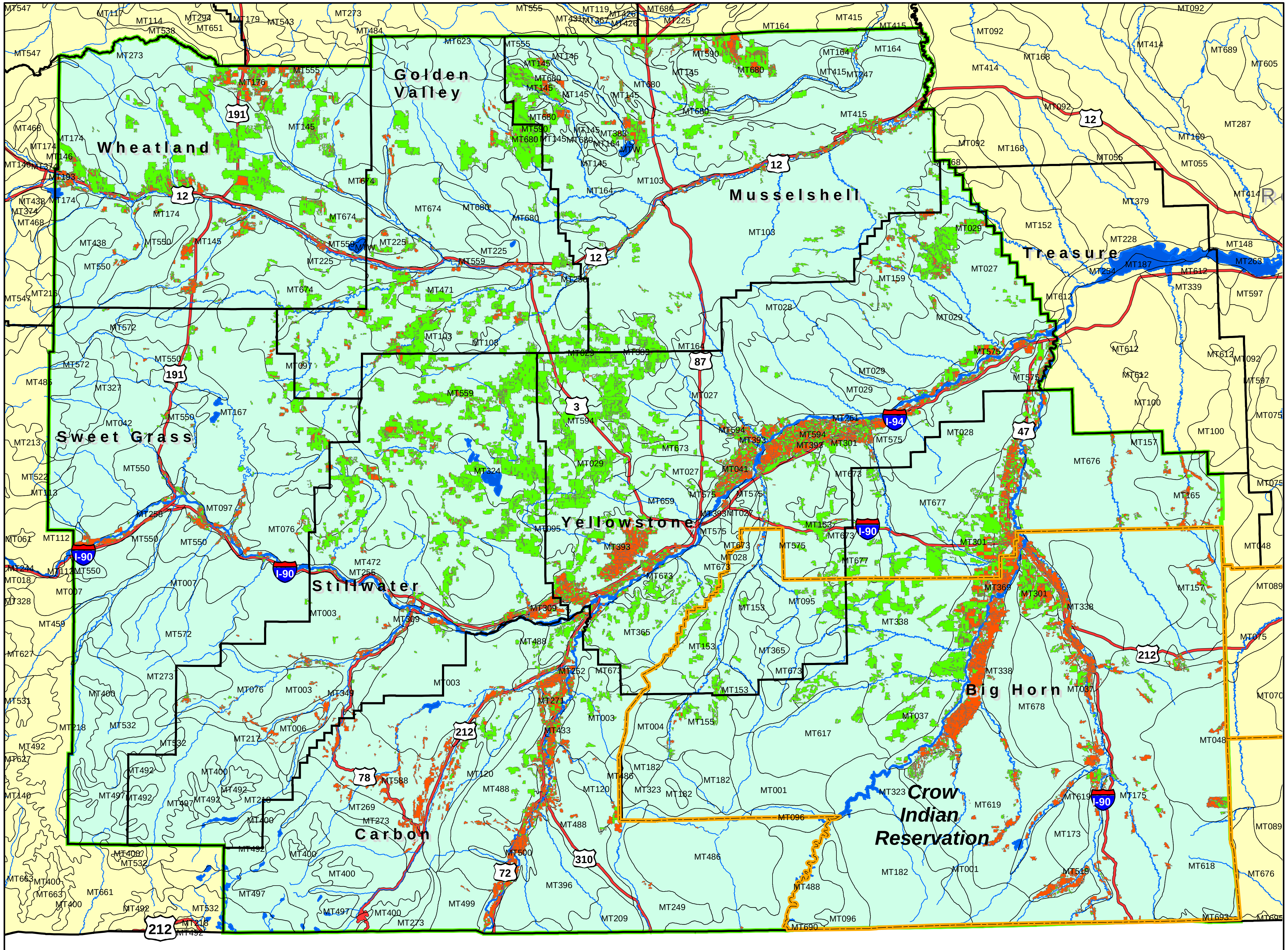
EXHIBIT 6
PRINCIPAL CROPS IN STUDY AREA

Crop	Irrigated (acre)	Non-Irrigated (acre)
Wheat	17,200	535,100
Barley	27,800	95,700
Oats	5,000	15,400
Corn	37,600	0
Sugar Beets	26,200	0
Alfalfa	139,500	279,500
Grass Hay	49,500	126,500

Source: Montana Department of Agriculture, Agricultural Statistics (2000) for 1999 Crop Year

The most common grass species are western wheatgrass, green needlegrass, needle-and-thread, little bluestem, blue grama, and sideoats grama. Various mid-and tall-grass species, such as switch-grass, Indiangrass, big bluestem, prairie sandreed, little bluestem, sand lovegrass, and needle-and-thread, are found in the sandhills with prairie cordgrass, rushes, and sedge in wetter sites (BLM 1992).

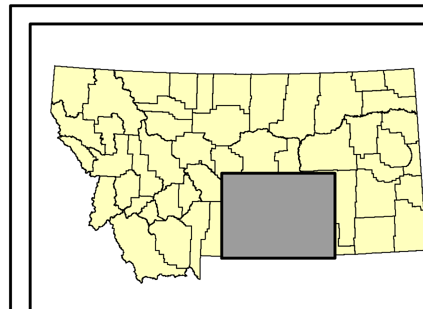
Exhibit 4: Agricultural Land Use Billings RMP Area



Legend

- Highways
- Rivers
- STATSGO Soils Map Unit
- Agricultural, Dry
- Agricultural, Irrigated
- Billings RMP Area
- Native American Reservations

Exhibit presents agricultural lands in the study area both dry and irrigated. Most of the irrigated land is located in the river and stream valleys. Some dry farming occurs on the higher terraces above the valleys.



Location Map

Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

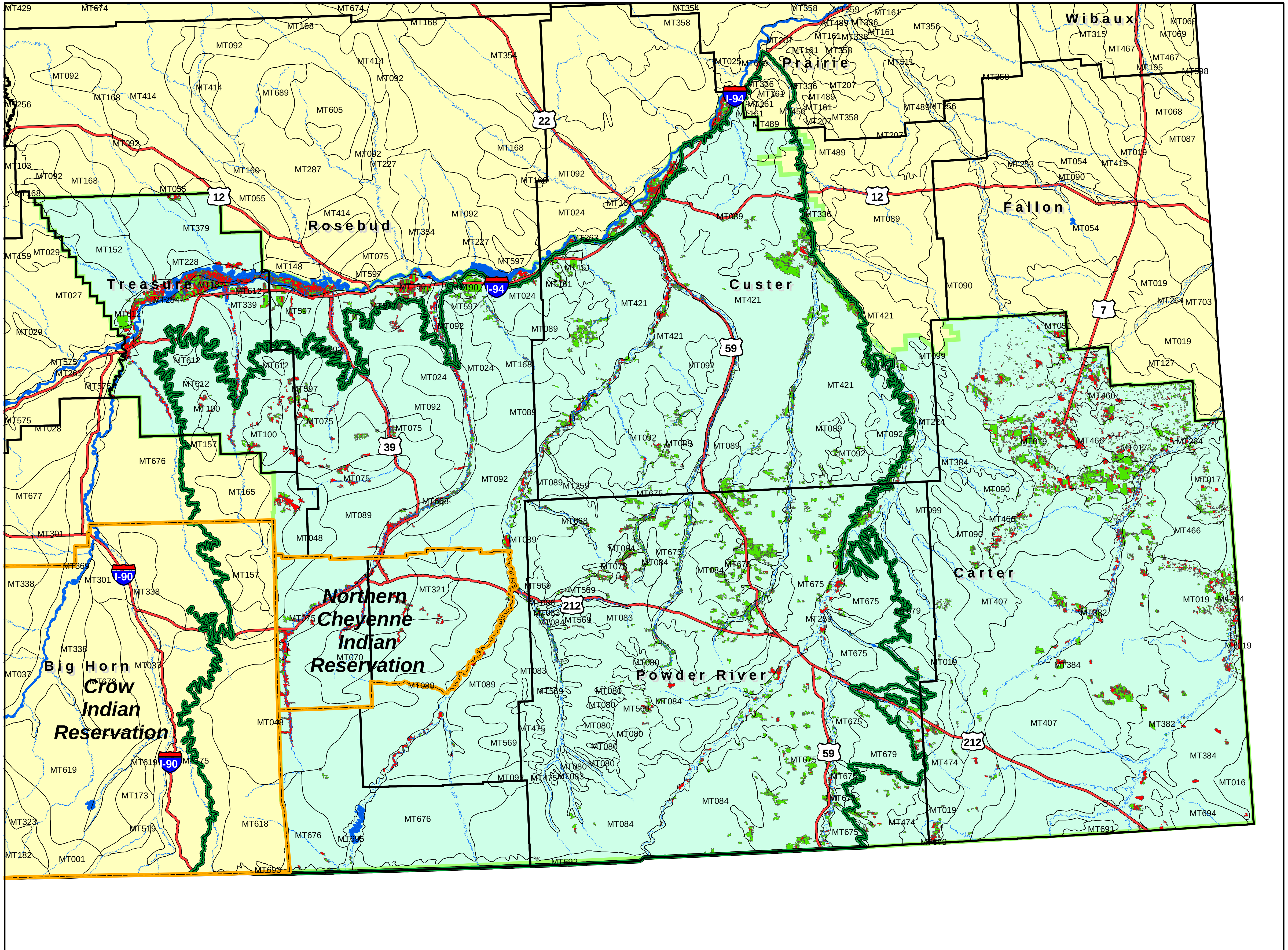
1:880,000

20 10 0 20 Miles

20,000 10,000 0 20,000 40,000 Meters

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.
Agricultural Lands: Montana GAP Analysis.

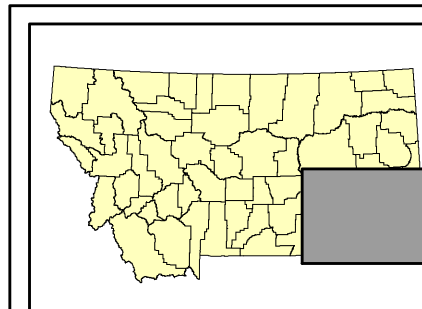
Exhibit 5: Agricultural Land Use Powder River RMP Area



Legend

- Highways
- Rivers
- STATSGO Soils Map Unit
- Powder River Geologic Basin Boundary
- Powder River RMP Area
- Agricultural, Dry
- Agricultural, Irrigated
- Native American Reservations

Exhibit presents agricultural lands in the study area both dry and irrigated. Most of the irrigated land is located in the river and stream valleys. Some dry farming occurs on the higher terraces above the valleys.



Location Map

Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

1:980,000

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.
Agricultural Data: Montana GAP Analysis Data.

CHAPTER 3: POTENTIAL IMPACTS OF CBM WATER USE

For the purpose of this Technical Report, the primary intended use of the CBM water is for agriculture—principally crop irrigation, and possibly livestock watering. Other uses, such as landspreading, surface discharge, or subsurface injection, would basically be for disposal of the CBM water.

In this section, potential impacts are described. That is, general impacts that water can have on agricultural systems are described, but the specific impacts of CBM water on agricultural systems in the project area are *not* described until later in the report.

3.1 AGRICULTURAL IMPACTS

Potential uses of CBM water for which impacts could occur include irrigation and livestock watering. These uses are discussed in this section.

3.1.1 Agricultural Irrigation

The potential impacts from using water with relatively high salinity and/or SAR for crop irrigation are reduction in crop yields and/or damage to the structure of the soil. Also, some crops may be sensitive to certain trace elements that are present in relatively high concentrations in the irrigation water.

The reduction of crop yields from the use of high salinity water is typically caused by the inability of the crop's roots to extract the water from the soil for plant growth, causing a yield reduction. The increasing salt concentration in the soil water causes an increasing "pull" on the water that competes with the plant root's "pull", resulting in lower water (and nutrient) uptake by the plant. Different crops exhibit varying tolerances to this effect.

Damage to the soil structure can occur when the irrigation water contains a high amount of sodium in relation to the amounts of calcium and magnesium. The measure of this relationship is called the SAR. The application of water with a high SAR to the soil can cause the soil particles to disperse, which results in clogging of soil pores and sealing of the soil. The effect of elevated SAR is dependent on irrigation water salinity: the lower the salinity, the more potent the effect of high SAR. In this condition, the water cannot enter (infiltrate) the soil in sufficient amounts to provide water to the crop plants. Soils with higher percentages of clay are more vulnerable to this effect. This sealing can also cause excessive runoff and erosion.

Elevated levels of sodium in the irrigation water can also directly affect certain plants. This effect is most common when sprinkler irrigation is used. Irrigation water that wets plant leaves may cause specific ion toxicity problems. This occurs primarily during periods of high temperature and low humidity when excess chloride and sodium can accumulate on the leaves by foliar absorption. The more frequent the wetting and drying cycles, the greater the leaf damage. Many crops seem to tolerate salinity equally well during seed germination and later growth stages. However, the salt tolerance of some crops does change with growth stage (Maas and

Hoffman 1977). For example, barley, wheat and corn are more sensitive to salinity during early seedling growth than during germination or larger growth stages, while sugarbeets and safflower are relatively sensitive during germination. Tolerances can also vary between plant varieties, such as with soybeans.

The presence of relatively high concentrations of some trace elements (for example, boron) in the irrigation water can cause toxicity in some crop species. While this is typically rare for most groundwater, it should be considered with a new water supply.

3.1.2 Livestock Water

Water for livestock on the farm or ranch typically comes from the irrigation water source, or from water in drainageways and streams. Although it is rare, problems can occur from high salinity, high magnesium, or high levels of certain toxic substances in the livestock drinking water. These are discussed in more detail later in Section 4.1.2.

3.2 OTHER IMPACTS

Other potential impacts from using CBM water can occur. From the standpoint of the CBM water producer, these impacts relate basically to the disposal of CBM water rather than impacts resulting from its beneficial use. They include landspreading and surface discharge to drainageways or streams.

Landspreading would occur when the CBM water is released on the ground surface and allowed to seek its own outlet, or is released into a diked or pond area for percolation into the ground or evaporation. The potential impacts of these practices would include discharge of salts to the groundwater (depending on the rate of infiltration and effective recharge of usable groundwater) and accumulation of salt on the surface that would likely have to be disposed in accordance with specific regulations. Also, erosion and associated sedimentation could occur from the additional flow in the drainageways. Changes in drainageway hydrology, and the characteristics of the CBM water, would likely affect native plant communities' composition and levels of productivity, influencing terrestrial and riparian habitat. These influences could be positive in dry habitat, where water increases primary productivity, or adverse where CBM water quality decreases productivity. Additionally, the higher salinity and SAR in the CBM water could alter the quality of the receiving waters. This last effect is not addressed in this report, but rather in a complementary *Water Resources Technical Report* (ALL 2001). It should be noted that any changes in state surface waters that violate the Water Quality Act will require a Montana Pollutant Discharge Elimination System (MPDES) permit.

The actual construction of the CBM wells and peripheral facilities could also have a potential impact on area resources and land use. Erosion must be controlled when disturbing land during construction of roads, pipelines, and other facilities necessary for CBM production. Also, care must be taken to avoid transport of noxious weed propagules. New facilities can also reduce the quantity of land available for agricultural use for crops and livestock.

CHAPTER 4: IMPACT ANALYSIS

Impacts to agricultural systems, and to other aspects of the land resource, are evaluated in this section.

It should be noted that for this analysis, it has been conservatively assumed that undiluted CBM water will be used year-round. The low rates of flow from most CBM wells would likely permit the blended or intermittent use of CBM water, which could reduce or eliminate the level of impacts suggested in this analysis. The use of CBM water for irrigation will also be limited to the growing season for the intended crops, which usually ranges from 100 to 150 days per year.

4.1 AGRICULTURAL IMPACTS

The main agricultural land uses evaluated here are livestock watering and irrigation. Appendix B presents several fact sheets prepared by the Montana State University Extension Service. These Ag Notes cover such topics as irrigating with saline water, soil erosion, soil quality, management of saline and sodic soils, suitability of water for livestock, and soil salinity crop and forage tolerances. Some of these documents were used to prepare this section, and all can be used as additional sources of information.

4.1.1 Agricultural Irrigation

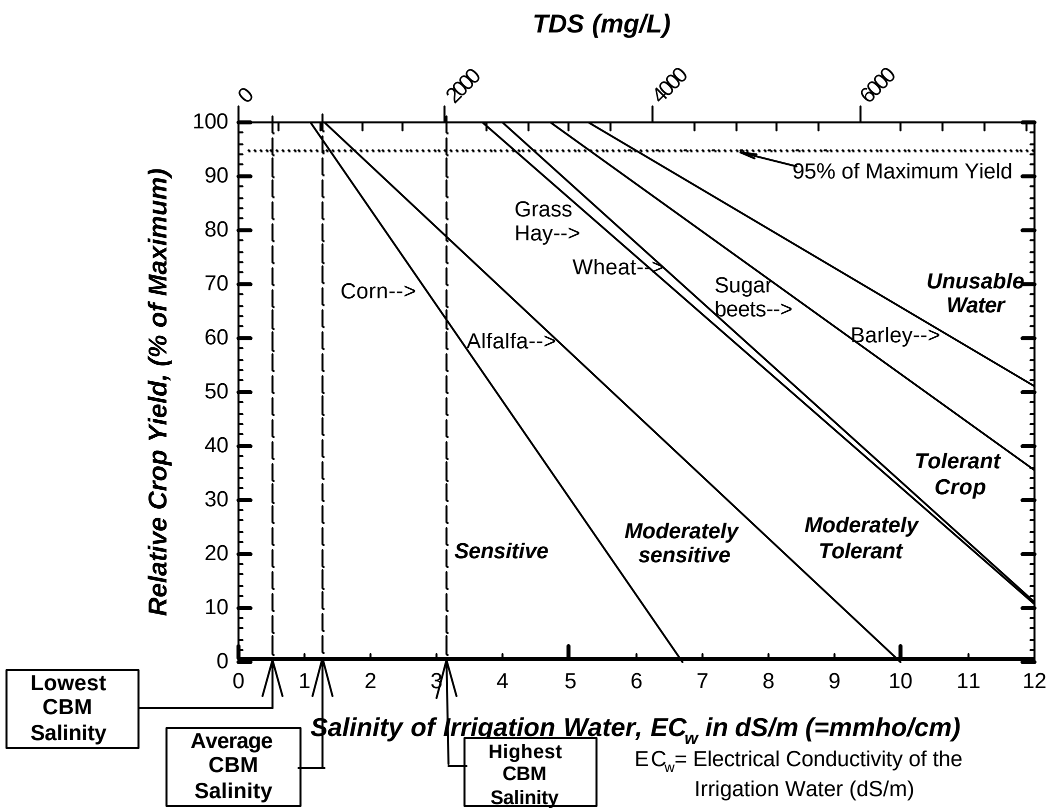
Potential impacts from agricultural irrigation with CBM water are related to the quality of the water. To determine these impacts, the quality characteristics of the CBM water can be compared to generally accepted irrigation water quality requirements (Ayers and Westcot 1985). The quality categories are discussed and compared to the previously presented CBM water quality characteristics as follows:

Salinity (*affects crop water availability*): The principal measure of salinity of irrigation water is EC expressed in deciSiemens per meter (dS/m). (Note: 1 dS/m = 1 mmhos/cm). Crops vary in their response to irrigation water salinity as follows:

- ?? < 0.7 dS/m provides no restrictions to crop growth
- ?? 0.7 – 3.0 dS/m provides slight to moderate restrictions to crop growth
- ?? > 3.0 dS/m provides severe restrictions to crop growth

From Exhibit 2, the lowest, mean (average), median, and highest salinities of the CBM water are 0.47, 1.3, 1.13, and 3.02 dS/m, respectively. From Exhibit 3, the average salinity of the CBM water from the 19 Decker wells is 2.39 dS/m. Based on these values, CBM water with salinities equal to those of the indicated lowest and average salinities would pose no significant problem even for most sensitive crops. CBM water with the highest indicated salinity may pose problems only to some moderately sensitive to moderately tolerant crops.

The tolerances to salinity of six example crops grown in the study area are shown in Exhibit 7. In developing the basic data used for Exhibit 7, Ayers and Wescott (1985) assumed a leaching fraction of 15 percent to 20 percent. The line indicating 95 percent of potential yield is also shown. Since the basic data are somewhat empirical, and since many other elements of the crop environment can also effect yield, it is considered reasonable that comparisons can, from a practical standpoint, be made using this indicated level of yield as a no-impact point. It is doubtful that such a yield decrement could be detected as attributed only to the level of salinity in the soil. Also from a practical standpoint, it is likely that farmers will alter their management practices (i.e., ensuring adequate leaching or selecting appropriate crop cultivars) to fit the specific conditions that occur to maximize the crop yield.



Source of basic data and original graphic:
Ayers R.S., and D.S. Wescott. 1985. Water Quality for Agriculture FAO Paper 29.
Tanji K.K. 1990. Agricultural Salinity Assessment and Management, ASCE Manual No. 71.
Shannon M.. 1996. Personal Communications. U.S. Salinity Laboratory, USDA, Agricultural Research Service, Riverside, CA.

Exhibit 7. Relationship Between Relative Crop Yield and Irrigation Water Salinity for Six Sample Crops

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With normally accepted management practices, the lowest CBM water salinity would have no adverse effect on the example crops. For the more salinity-sensitive of the example crops, such as alfalfa and corn, the salinity level of the average CBM water is near the threshold of causing yield reduction, and care would have to be taken to ensure adequate leaching. Also, a portion of the irrigation water supply may have to come from other sources, probably current irrigation water sources. From the standpoint of salinity, the other example crops should do well with any of the indicated CBM water as a sole source for irrigation, provided the soil has good internal drainage and normally acceptable management practices are followed**.** Prospective irrigators should be provided with this information in order for them to make the decision if they can accept a possible yield reduction, or possible increase in the case where a crop goes from dryland to irrigated.

SAR (Sodicity) (*affects infiltration rate of water*): Generally, increasing levels of SAR create an increasing hazard for infiltration problems. However, if the irrigation water contains higher levels of salinity, the SAR can increase without greatly increasing the infiltration hazard. Therefore, both the SAR and the EC of the irrigation water are used to evaluate potential infiltration problems. Usually, SAR values below 3.0 are not considered to be a threat to crops and native plants; however, SAR values above 12.0 are considered sodic and may affect soils and vegetation.

Exhibit 8 shows the potential infiltration hazard of the average CBM water quality from Exhibits 2 and 3. Such water may cause a slight to moderate reduction of the rate of infiltration of water into the soil. Also shown in Exhibit 8 are the individual CBM waters (Rice et al, 2000) with the lowest and highest salinity (EC) with their corresponding SAR, and those with the lowest and highest SAR and their corresponding EC. The individual waters with the highest SAR and lowest EC could cause a significant reduction in the infiltration rate if the waters were used continuously as the only water supply. The individual waters with the lowest SAR and the highest EC would likely cause only a slight to moderate reduction in the infiltration rate of the soil.

Trace Elements (*affects crop toxicity*): Certain trace elements in the irrigation water can cause toxicity in certain crops. Ayers and Westcot (1985) present recommended maximum concentrations of trace elements in irrigation water. A comparison of these recommended maximum concentrations to the highest concentrations presented in Exhibit 2 showed that, in every case, the highest concentrations of the CBM waters were considerably lower, in most instances by one to three orders of magnitude, than the recommended maximums.

4.1.2 Livestock Watering

As with plants, certain trace elements in drinking water can be toxic to livestock. Ayers and Westcot (1985) present water quality guidelines for livestock. A comparison of these water quality guidelines to the highest concentrations of the CBM waters in Exhibit 2 and the average concentrations of the CBM water in Exhibit 3 indicated that all of the CBM waters would be very satisfactory to excellent for use as livestock drinking water. In some cases, the water could cause temporary diarrhea in livestock not accustomed to such water, but this problem should rapidly disappear as animals adapt to the new water supply. Ag Note 146 - *Suitability of Water for Livestock* in Appendix B also provides information pertaining to suitable water for livestock.

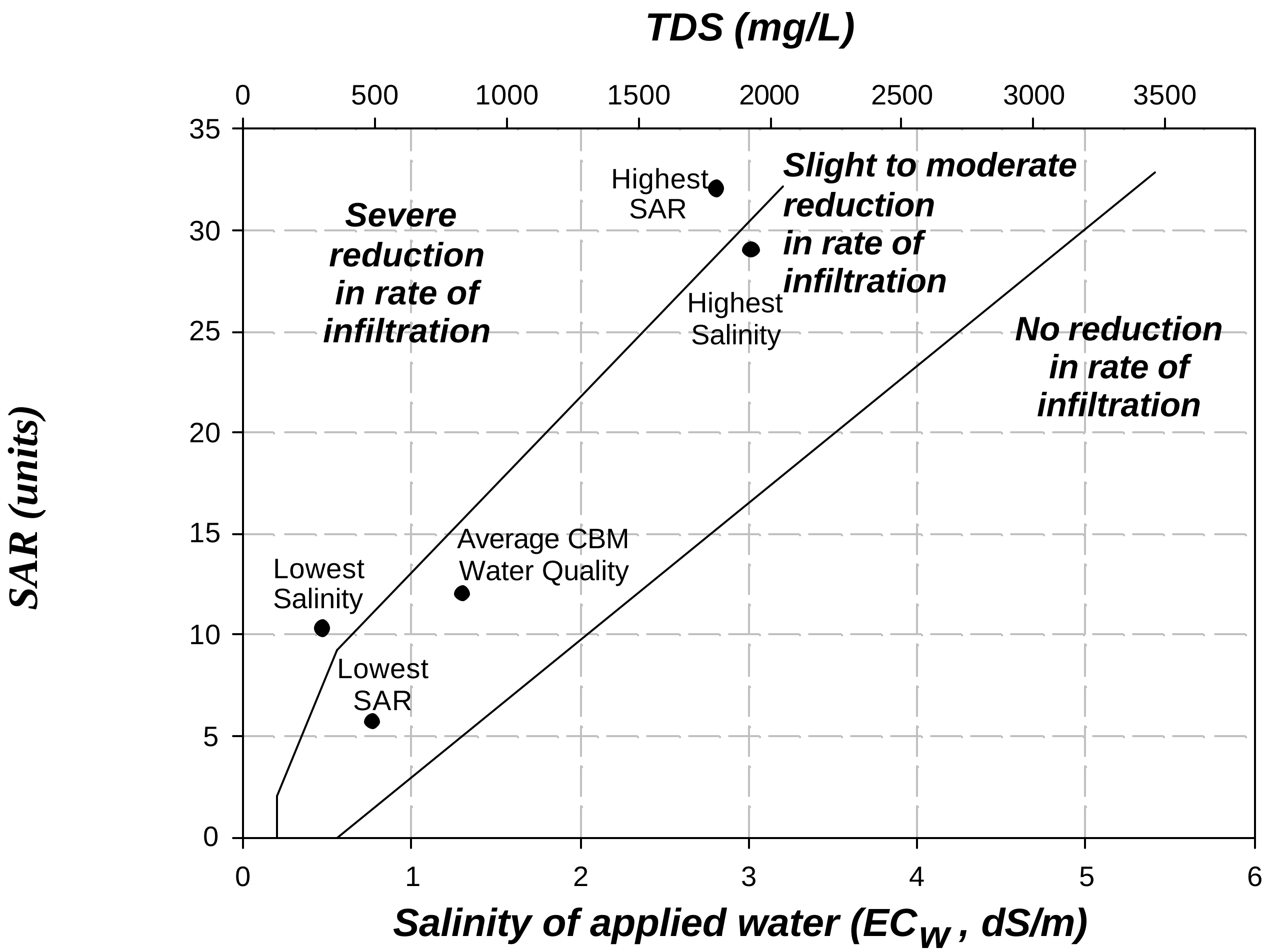

Exhibit 8. General CBM Water Quality Relative to the Potential for Dispersion of Soil Aggregates and Reductions in Soil Rate of Infiltration (Based on data from Ayers and Westcot 1985)

4.2 OTHER IMPACTS

In addition to supplying water to plants or livestock, landspreading or surface discharge of the CBM water can cause undesirable impacts. Where irrigation water is otherwise unavailable or not supplied, discharge of CBM water to land would have the benefit of providing water for plant growth. With the higher salinity CBM waters shown in Exhibits 2 and 3, long-term landspreading would likely increase the salinity and sodicity of the affected surface soils and hence adversely affect the native vegetation and wildlife habitat. This could lead to an increase in primary productivity of plant communities adapted to this new hydrologic condition or changes in the existing plant community in response to the new hydrologic regime. Resulting communities and habitat would necessarily be adapted to the quality of water from the specific CBM source wells. This could lead to subsequent changes in the wildlife community to one adapted to salt-tolerant plant communities. Accumulation of evaporated salts could also occur in any closed depressions, which would destroy vegetation in these depressions. Such long-term discharge to the land surface could also cause excessive erosion of the soil and gullying, which could intensify over time if high SAR water reduced infiltration. With long-term discharge of high salt CBM water to constructed evaporation ponds, removal and disposal of the accumulated salts would likely be required.

With discharge of the CBM water to surface drainageways and streams, serious erosion could occur, damaging or destroying instream vegetation (Bauder 1999). The erosion can result in increased sediment loads, which along with the potential high salinity and sodicity, can significantly degrade the stream and receiving water quality. This degraded quality could also affect the biological aspects of the stream. It is also important to note that, depending on the quantity and level of quality of the discharged CBM water, the receiving waters could significantly dilute the concentrations of the constituents in the CBM water, resulting in potentially minimal impact from salinity on the receiving waters. Of course this would depend on the amount of CBM water released in relation to the flow in the receiving water bodies. Bauder (1999) presented a scenario based on the assumption that 100 CBM wells producing 10 gallons per minute (gpm) each for a total of 2.2 cubic feet per second (cfs) were discharging into the Tongue River near Decker, Montana. The mean flow of the river at the lowest period is about 180 cfs, and during the high flow it is about 1,680 cfs. In terms of volume of water, the CBM water discharges are likely to be insignificant compared to the normal flows of the Tongue River. On the other extreme, the RFD produced by the Miles City, Montana, BLM in 2001 gives the full field development of a maximum of 26,000 wells in the next 20 years. At an average flow of 10 gpm per CBM well, this would be approximately 580 cfs (1,150 ac-ft/day), which could make a significant impact on the environment.

The construction and continued use of the CBM wells and gas production facilities, the network of roads and pipelines, and storage ponds can cause significant impacts to the local resources. The actual surface disturbances and use of the facilities can cause erosion of the soils and introduction of noxious weeds to the surrounding area. The existence of the facilities reduces the forage base for livestock and wildlife. The activities during use of the facilities can also adversely affect the activities of the various native wildlife species.

4.3 LONG TERM EFFECTS

The long-term impacts of using CBM water or diluted discharge water for agricultural purposes include crop effects, farming practice changes, irrigation management, and direct effects to soils. However, with proper crop selection and appropriate irrigation management, economic yields can be sustained under low to moderate saline conditions.

The use of high salinity/sodium CBM water may have long-term effects on crops. There may be limitations on which crops species can viably be grown. More salt tolerant crops may have to be grown where higher salinity irrigation water is used, such as barley and sugar beets, and hays such as Bermuda, wheatgrass and wildrye, instead of the more salt sensitive plants like wheat, alfalfa, corn, and clover hay. Some crops may show toxic effects of salts accumulating in the leaves or rootstock over time. This is most common in trees and other woody perennials.

Another long-term effect of using high salinity CBM water may lead to the modification of cropping practices. This may include such practices as modifying seed placement (e.g., planting on furrow sides, double-row raised beds, increasing seeding rates, etc.) to achieve better germination and stands; new or modified equipment for crop sowing; growing different crops; soil profile modification for better drainage and water penetration; and the use of amendments such as gypsum or sulfur to soils to improve water permeability lost to excess sodium in the soil.

Soils do not usually become excessively saline from use of saline water in a single irrigation season, depending on the quality of water used. It may even take several irrigation seasons to affect the level of salt in the soil solution. The maximum soil salinity in the root zone that results from continuous irrigation with saline water does not occur when salty water is used only a fraction of the time. Changes may need to be made to irrigation water management techniques required to use CBM water. The method of application of irrigation water may need to change. Areal application with sprinkler irrigation can cause concentrated salt accumulations near the soil surface and cause foliar damage to certain plants. Other types of application such as drip and furrow irrigation have less salt accumulation at the soil surface in the shorter term, but still may result in salt accumulations in deeper soils over the longer term. Additional irrigation water will be required for leaching to ensure salts are moved out of root zone. Increasing the frequency of irrigation may also need to be implemented to maintain soil water content and decrease the effects of applying saline water (less water holding capacity and higher salinity levels). These increases in irrigation water amounts may lead to producers having to file for additional water rights or finding other sources of lower salinity water for leaching, and a potential for more saline seeps in areas irrigated with CBM water.

The cumulative effects of the application of high SAR CBM water to the soil and the build up of sodium will have an affect on the physical characteristics of the soils -which in turn affect the chemical characteristics – and then the biological characteristics. It is possible to create a site through sodium saturation which will not support the production of very many plant species. This is not so much a consequence of the sodium as it is a consequence of the externalities, i.e., the things that come about when the soil is saturates with sodic water and it disperses (deflocculates). This includes a shut down of the water and gas exchange processes. The soil is likely to go from and aerobic situation to an anaerobic (oxygen devoid) system. High SAR/sodic water should not be applied to fine textured, slow infiltration, poorly drained soils. This would include silts, clays, silt loams, silty clay loams, clay loams, sandy clays. These soils are dependent on good structure for infiltration. If sodic water is applied to these soils, the probability of soil dispersion (deflocculation) is high. Once the soil disperses, infiltration and drainage decrease. The long-term consequence is an anaerobic, waterlogged, saline/sodic soil. These soils can be reclaimed, but the requirement is engineered drainage and the application of excessive amounts of gypsum, sulfur, and good quality water - and the discharge of the sodium laden drainage water.

Because of its lack of structure and vegetation, dispersed soil is very susceptible to erosion. Depending on the location of the CBM water discharge and the drainage course, a normal rain or storm event could easily provide the flow rate and runoff necessary for erosion on a large scale of the already dispersed, saturated, sodic soils.

The soil's dispersion takes place through out the profile. So, the erosion will continue to a point where the profile has not been exposed to the sodic water or it reaches a basement pavement structure that cannot be dispersed or eroded, like coarse gravels or bedrock. In any single drainage, the above scenario could take place repeatedly with down cutting and erosion that would continue until the soil profile is completely eroded away and what is left behind is a "V" shaped cut with bedrock in the bottom. Water will also infiltrate within the ephemeral channels and streambanks, which will contribute to increased erosion in the drainages over time. Another long-term effect includes saline seeps that may appear on lower terraces, river banks, and below impoundments where high SAR water flows or is stored. This may result in varying degrees of adverse effects on vegetation, consumers of that vegetation, the soil, and water quality of any streams receiving salts from such seeps. The native species composition in these effected areas will also change. CBM water discharge will have the cumulative effect of encouraging the establishment and proliferation of non-native and noxious weed species like Salt Cedar that thrive and dominate under high sodic/salt conditions.

Development of a sodium hazard usually takes time. Soil tests for SAR or percent exchangeable sodium can detect changes before permanent damage occurs. Proper management can maintain SAR and salinity values at a steady state below threshold levels.

CHAPTER 5: FINDINGS

Based on an evaluation of the impact analysis discussed previously, and assuming that the water quality data presented in Exhibits 2 and 3 are representative of all CBM water in the study area, it is apparent that, at least in general, CBM water can be used in agriculture. Certainly it is acceptable for livestock water and there would be no danger from trace elements when it is used for crop irrigation.

5.1 AGRICULTURAL IRRIGATION

Some of the CBM water, that with the lower salinity and SAR, could likely be used as a sole irrigation water source for many of the crops in the area grown in the coarser textured, well-drained soils. Special management practices would likely be necessary to use the higher salinity CBM water on the more sensitive crops. These practices would include assuring adequate leaching and possibly using better quality water for part of the irrigation season. This in effect would be a dilution of the constituents in the CBM water.

The moderate to high SAR in most of the CBM water would cause the greatest problem in using it for agricultural irrigation. Careful monitoring of the soil would be advisable. When sodium levels in the soil become high and infiltration of the water into the soil becomes obviously slower, special management practices would have to be implemented. These practices would include adding a calcium source, such as gypsum, to displace the sodium, and assuring adequate leaching. If better quality water were used to accomplish the leaching, the results may be faster. The extra leaching would likely mitigate the potential increase in salinity that could occur from adding the gypsum.

The data from the CBM wells shown in Exhibits 2 and 3 demonstrate that the quality of the CBM water can vary considerably. The variation may be greater when thousands of wells are developed. If water with the lower to average salinity and SAR levels were available, there would be little problem in using the CBM water for agricultural irrigation. From a practical point of view, if only the poorer quality water was available, it would not likely be advisable to use it for irrigation, unless it were diluted or applied intermittently. The quality of the water from each unit or group of wells would have to be determined before specific recommendations for its use could be made.

5.2 SURFACE WATER DISCHARGE

Discharging the CBM water into surface streams and rivers may be acceptable under some circumstances. The quality constituents in low flows of CBM water may be diluted sufficiently to cause little concern of increasing the salinity or sodicity of the much larger flows of the receiving waters. However, when greater numbers of CBM wells are constructed and the flows increase substantially, discharge into the streams and rivers may become indefensible. If CBM flows were discharged into smaller drainageways and streams, it would have to be well controlled to minimize erosion and harm to riparian vegetation and aquatic habitats.

5.3 LIVESTOCK WATERING

It doesn't appear that CBM discharge water will harm livestock. The upper salinity limits for livestock is 10,000 mg/L. Livestock can tolerate and use water with TDS up to several thousand mg/L, with 3,000 mg/L set as the maximum goal by the MDEQ (Bauder 1999). Livestock should initially be monitored after providing CBM water since in some cases, the water could cause temporary diarrhea in livestock not accustomed to such water, but this problem should rapidly disappear as animals adapt to the new water supply.

5.4 OTHER IMPACTS

Impacts from the construction of roads, pipelines and drilling pads, and operation of the CBM gas and water production facilities will need to be minimized and mitigated. With careful management practices, impacts can likely be minimized and mitigated to an acceptable degree. The impacts caused by discharging the poorest quality CBM water to the surrounding land surface would be very difficult to mitigate, making the practice undesirable.

It is also important to understand that the discharges and uses of CBM water are regulated. MDEQ issues discharge permits (MPDES) for the use and/or discharge of the CBM water. A determination of the acceptability of CBM water will have to be made for each individual project on a site-specific basis.

BOI011020011.DOC/LH

CHAPTER 6: REFERENCES

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APPENDIX A

STATE SOIL GEOGRAPHIC DATABASE (STATSGO) DATA FOR MONTANA SOILS

Source: U.S. Department of Agriculture, Natural Resource Conservation Service (USDA NRSC). 1996 (1998). The State Soils Geographic Database (STATSGO) (for Montana). Acquired from the Internet: http://www.ftw.nrcs.usda.gov/stat_data.html.

?? Exhibit A-1: STATSGO Soils Types, Billings RMP Area

?? Exhibit A-2: Areal Extent of Soil Map Units for Billings RMP Area

?? Exhibit A-3: Soil Series Characteristics for Billings RMP Area

?? Exhibit A-4: STATSGO Soils Types, Powder River RMP Area

?? Exhibit A-5: Areal Extent of Soil Map Units for Powder River RMP Area

?? Exhibit A-6: Soil Series Characteristics for Powder River RMP Area

?? Exhibit A-7: Mean Soil K-factor by STATSGO Map Unit, Billings RMP Area

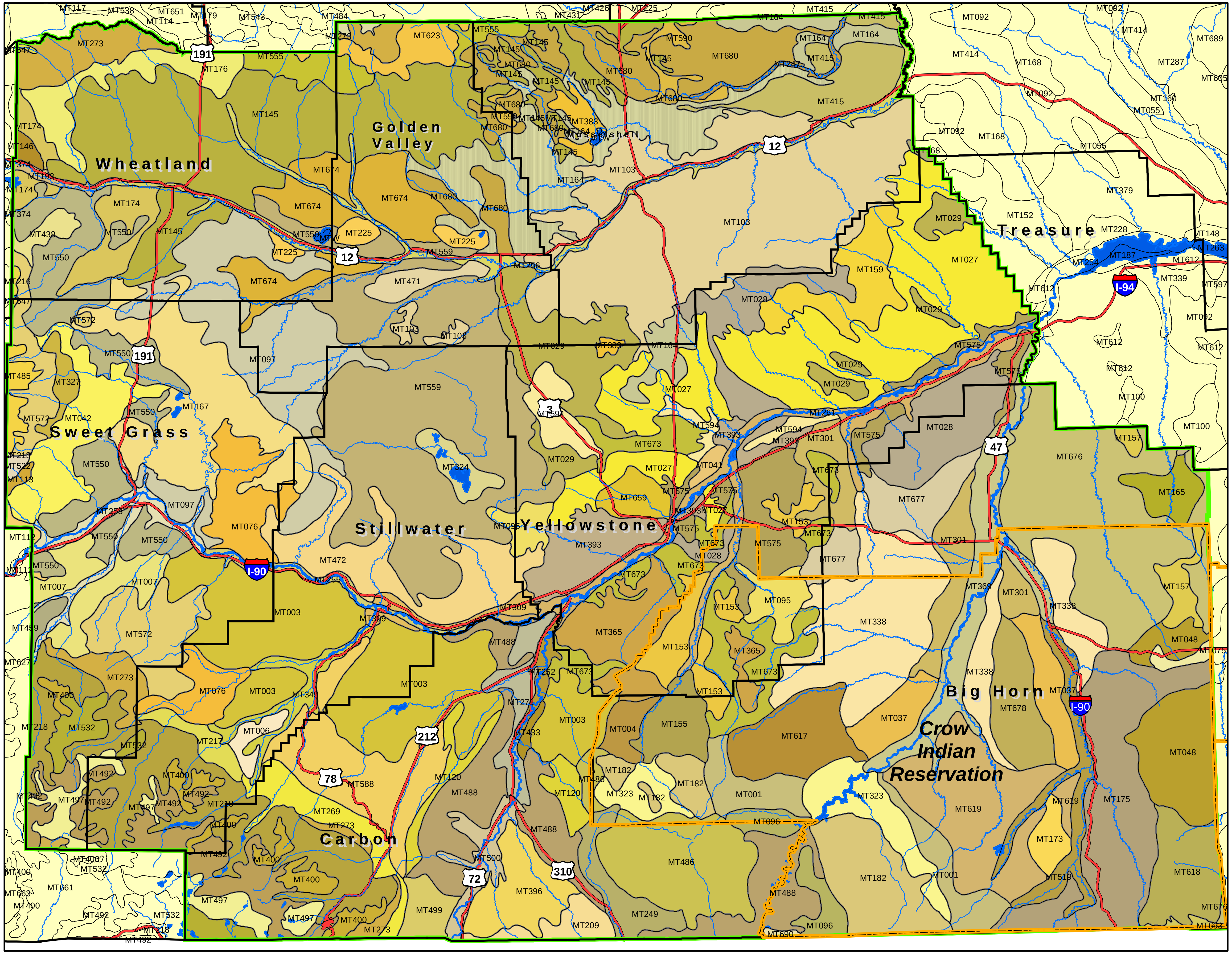
?? Exhibit A-8: Mean Soil K-factor by STATSGO Map Unit, Powder River RMP Area

?? Exhibit A-9: Mean Soil Salinity by STATSGO Map Unit, Billings RMP Area

?? Exhibit A-10: Mean Soil Salinity by STATSGO Map Unit, Powder River RMP Area

?? Exhibit A-11: Statewide Maximum Soil SAR by STATSGO Map Unit

Exhibit A-1: STATSGO Soils Types Billings RMP Area

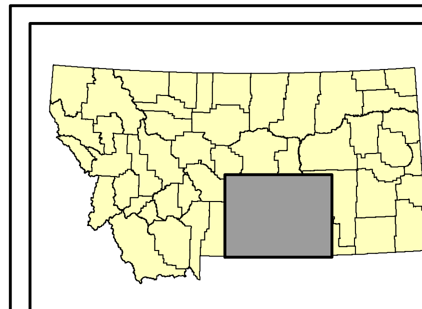


Legend

- Rivers
- Highways
- Billings RMP Area
- Native American Reservations

Map Unit

MT001	MT175	MT459
MT003	MT176	MT471
MT004	MT182	MT472
MT006	MT193	MT484
MT007	MT209	MT485
MT027	MT213	MT486
MT028	MT216	MT488
MT029	MT217	MT492
MT037	MT218	MT497
MT041	MT225	MT499
MT042	MT247	MT500
MT048	MT249	MT519
MT075	MT252	MT522
MT076	MT255	MT532
MT092	MT256	MT538
MT095	MT258	MT547
MT096	MT261	MT550
MT097	MT269	MT555
MT100	MT271	MT559
MT103	MT273	MT572
MT112	MT301	MT575
MT113	MT309	MT588
MT114	MT323	MT590
MT120	MT324	MT594
MT145	MT327	MT617
MT146	MT338	MT618
MT152	MT349	MT619
MT153	MT365	MT623
MT155	MT369	MT659
MT157	MT374	MT661
MT159	MT383	MT673
MT164	MT393	MT674
MT165	MT396	MT676
MT167	MT400	MT677
MT168	MT415	MT678
MT173	MT433	MT680
MT174	MT438	MT690
		MT693
		MTW



Location Map

Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

1:850,000

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.

EXHIBIT A-2

AREAL EXTENT OF SOIL MAP UNITS FOR BILLINGS RMA

STATSGO Map Unit	Acres	% Area	STATSGO Map Unit	Acres	% Area	STATSGO Map Unit	Acres	% Area
MT001	93,754	0.87	MT176	73,711	0.68	MT472	149,344	1.38
MT003	436,268	4.04	MT182	147,700	1.37	MT484	3,611	0.03
MT004	23,322	0.22	MT193	8,546	0.08	MT485	21,066	0.20
MT006	15,901	0.15	MT209	31,675	0.29	MT486	159,584	1.48
MT007	70,560	0.65	MT213	298	<0.01	MT488	236,799	2.19
MT027	424,075	3.93	MT216	2,132	0.02	MT492	127,770	1.18
MT028	205,254	1.90	MT217	22,544	0.21	MT497	68,075	0.63
MT029	171,071	1.59	MT218	257,150	2.38	MT499	28,655	0.27
MT037	83,773	0.78	MT225	26,205	0.24	MT500	40,683	0.38
MT041	8,032	0.07	MT247	10,450	0.10	MT519	68,982	0.64
MT042	107,565	1.00	MT249	48,815	0.45	MT522	4,497	0.04
MT048	123,830	1.15	MT252	16,832	0.16	MT532	48,413	0.45
MT075	9,025	0.08	MT255	25,454	0.24	MT538	25	<0.01
MT076	121,597	1.13	MT256	88,473	0.82	MT547	1,244	0.01
MT092	10	<0.01	MT258	50,431	0.47	MT550	227,202	2.11
MT095	57,076	0.53	MT261	111,403	1.03	MT555	53,564	0.50
MT096	43,281	0.40	MT269	58,449	0.54	MT559	567,531	5.26
MT097	283,471	2.63	MT271	43,967	0.41	MT572	142,349	1.32
MT100	846	0.01	MT273	126,307	1.17	MT575	140,714	1.30
MT103	577,016	5.35	MT301	112,102	1.04	MT588	149,865	1.39
MT112	5,667	0.05	MT309	23,490	0.22	MT590	22,004	0.20
MT113	4,089	0.04	MT323	104,714	0.97	MT594	60,705	0.56
MT114	3	<0.01	MT324	28,542	0.26	MT617	91,333	0.85
MT120	47,803	0.44	MT327	17,866	0.17	MT618	78,598	0.73
MT145	545,006	5.05	MT338	303,030	2.81	MT619	186,591	1.73
MT146	7,046	0.07	MT349	39,683	0.37	MT623	41,880	0.39
MT152	12	<0.01	MT365	116,071	1.08	MT659	29,616	0.27
MT153	72,675	0.67	MT369	141,367	1.31	MT661	3,050	0.03
MT155	49,063	0.45	MT374	7	<0.01	MT673	179,618	1.66
MT157	30,028	0.28	MT383	23,594	0.22	MT674	147,969	1.37
MT159	84,373	0.78	MT393	103,536	0.96	MT676	325,430	3.02
MT164	278,907	2.58	MT396	76,447	0.71	MT677	82,348	0.76
MT165	33,440	0.31	MT400	56,548	0.52	MT678	70,647	0.65
MT167	216,026	2.00	MT415	93,856	0.87	MT680	214,696	1.99
MT168	2,477	0.02	MT433	5,480	0.05	MT690	2,718	0.03
MT173	22,680	0.21	MT438	16,109	0.15	MT693	5,734	0.05
MT174	72,377	0.67	MT459	9,292	0.09	MTW	2,525	0.02
MT175	230,386	2.14	MT471	24,662	0.23			

* Acreages are approximate - taken from 1:250,000 STATSGO Maps

EXHIBIT A-3

SOIL SERIES CHARACTERISTICS FOR BILLINGS RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
MT103	CABBART	loam	0.37	3	6-45	0-4	
(5.4 %)	DELPOINT	loam	0.37	3	15-35	0-4	
	CABBART	loam	0.37	3	6-45	0-4	
	YAMAC	loam	0.37	5	2-8		
	HAVRE	loam	0.37	8	0-2	0-2	
	HAVRE	loam	0.37	10	0-2	0-2	
	HARLEM	silty clay	0.32	10	0-2	2-4	
	TWILIGHT	fine sandy loam	0.2	4	2-15		
MT559	TANNA	clay loam	0.37	6	2-8		
(5.3 %)	RENTSAC	channery-loam	0.2	7	4-15		
	YAWDIM	clay loam	0.37	3	25-60		
	TANNA	clay loam	0.37	6	8-15		
	LAMBETH	silt loam	0.43	4	15-45		
	ABSHER	silty clay loam	0.43	5	0-6	4-8	1-5
	BIRNEY	channery-loam	0.2	5	25-45	0-2	
	BEENOM	loam	0.37	7	4-8		
	LARDELL	clay loam	0.37	8	0-2	16-16	8-50
	BONFRI	loam	0.37	7	2-8		
	LAMBETH	silt loam	0.43	4	2-8		
	ASSINNIBOINE	fine sandy loam	0.24	6	2-15		
MT145	CRAGO	loam	0.37	4	0-4		
(5.1%)	MUSSELSHELL	loam	0.37	3	0-2		
	CRAGO	gravelly-loam	0.2	4	0-4		
	ATTEWAN	loam	0.37	6	0-2		
	YAWDIM	silty clay	0.32	3	4-35		
	VERSON	clay loam	0.37	4	0-4		
	CRAGO	gravelly-loam	0.2	4	4-35		
	EVANSTON	loam	0.37	8	0-2		
	ETHRIDGE	clay loam	0.37	6	0-2		
	CABBART	loam	0.37	3	8-35	0-4	
	DELPOINT	loam	0.37	3	8-15	0-4	
MT003	ABSAROKEE	clay loam	0.32	8	2-8	0-2	
(4.0 %)	ABSAROKEE	clay loam	0.32	8	8-15	0-2	
	WAYDEN	clay loam	0.37	6	15-50	0-4	
	ABSAROKEE	clay loam	0.32	8	15-50	0-2	
	CASTNER	channery-loam	0.2	6	15-50		
	SINNIGAM	clay loam	0.37	6	2-15		
	SINNIGAM	clay loam	0.37	6	15-50		
	WORK	loam	0.37	6	4-8		
	HILGER	channery-sandy loam	0.15	5	25-60		
	CASTNER	stony-loam	0.2	6	25-60		
	WINKLER	gravelly-sandy loam	0.15	8	25-60		
	REEDER	loam	0.32	8	15-35		
	FARNUF	loam	0.37	7	4-8		
	WORK	loam	0.37	6	8-15		
	AMHERST	loam	0.37	5	4-15		
	CASTNER	loam	0.32	6	4-15		
	USTIC TORRIFLUVENTS	loam	0.37	7	0-4	0-2	
	GRAIL	clay loam	0.32	10	4-8	0-2	

Note: Only the top 15 Map Units based on total acreage are included (% in parnthesis). This represents 48% of the soils in the study area.

EXHIBIT A-3

SOIL SERIES CHARACTERISTICS FOR BILLINGS RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
MT027	BAINVILLE	loam	0.37	4	2-15		
(3.9 %)	CABBART	clay loam	0.32	3	4-35	0-4	
	MCRAE	loam	0.37	5	7-15	0-2	
	BAINVILLE	loam	0.37	4	7-30		
	TRAVESSILLA FAMILY	loam	0.32	2	4-15		
	MCRAE	loam	0.37	5	0-7	0-2	
	YAWDIM	clay loam	0.37	3	4-25		
	DAST	fine sandy loam	0.2	3	2-15		
	CUSHMAN	loam	0.37	7	1-7	0-2	
	LOTHAIR	silty clay loam	0.37	3	3-15	0-4	
	ABOR	clay loam	0.43	6	2-7	0-4	
	HAVRE	silty clay loam	0.32	8	0-4	0-2	
	LOTHAIR	silty clay loam	0.37	3	0-35	0-4	
	HARLEM	silty clay loam	0.37	10	0-4	0-4	0-4
	HAVRE	loam	0.37	8	0-4	8-16	0-4
	VANANDA	silty clay	0.37	3	1-7	4-8	1-12
MT676	YAWDIM	silty clay loam	0.37	3	8-35		
(3.3 %)	DELPOINT	loam	0.37	3	15-35	0-4	
	DELPOINT	loam	0.37	3	8-15	0-4	
	THURLOW	silty clay loam	0.32	4	0-8		
	MCRAE	loam	0.37	5	1-8	0-2	
	DELPOINT FAMILY	stony-loam	0.24	2	15-70		
	FORELLE	loam	0.37	4	8-15		
	DAST	fine sandy loam	0.2	3	2-15		
	HARLEM	silty clay loam	0.37	10	0-4	2-4	
	ABOR	clay	0.37	6	0-15	0-4	
	VANDA	clay	0.37	4	1-8	2-8	20-30
	GERDRUM	clay	0.37	4	0-8	0-2	
	VANDA FAMILY	clay loam	0.37	6	0-4	8-16	20-30
	TRAVESSILLA FAMILY	loam	0.32	2	2-15		
MT338	LISAM	clay	0.37	3	4-35	0-2	
(2.8 %)	ABOR	clay	0.37	6	4-15	0-4	
	VANDA	clay	0.37	4	0-8	2-8	20-30
	MARIAS	silty clay	0.37	6	0-8	0-4	1-4
	ABOR	clay	0.37	6	25-45	0-4	
	GERDRUM	clay	0.37	4	0-8	0-2	
	KEISER	silty clay loam	0.28	3	2-8		
	HYDRO	silty clay loam	0.32	7	0-8		
	LAMBETH	silt loam	0.43	4	8-15		
	HAVRE	loam	0.37	8	0-4	0-2	
MT097	CABBART	loam	0.37	3	8-35	0-4	
(2.6 %)	RENTSAC	channery-loam	0.2	7	8-35		
	DELPOINT	loam	0.37	3	8-15	0-4	
	TRAVESSILLA FAMILY	fine sandy loam	0.2	2	8-35		
	YAWDIM	clay loam	0.37	3	15-35		
	EVANSTON	loam	0.37	8	0-4		
	DELPOINT	loam	0.37	3	2-8	0-4	
	CAMBETH	silt loam	0.37	6	2-8		
	KOBAR	clay	0.32	6	2-4	0-2	1-5
	YAMAC	loam	0.37	5	2-8		
	ETHRIDGE	clay loam	0.37	6	2-8		
	CAMBETH	silt loam	0.37	6	8-15		

Note: Only the top 15 Map Units based on total acreage are included (% in parnthesis). This represents 48% of the soils in the study area.

EXHIBIT A-3

SOIL SERIES CHARACTERISTICS FOR BILLINGS RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
	MARMARTH	fine sandy loam	0.2	7	2-8		

Note: Only the top 15 Map Units based on total acreage are included (% in parnthesis). This represents 48% of the soils in the study area.

EXHIBIT A-3

SOIL SERIES CHARACTERISTICS FOR BILLINGS RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
MT164	DELPOINT	loam	0.37	3	2-15	0-4	
(2.6 %)	CABBART	loam	0.37	3	2-15	0-4	
	CABBART	loam	0.37	3	15-35	0-4	
	YAMAC	loam	0.37	5	2-15		
	HARLEM	silty clay	0.32	10	0-2	2-4	
	TWILIGHT	fine sandy loam	0.2	4	2-15		
	HAVRE	loam	0.37	8	0-2	0-2	
	GERDRUM	clay loam	0.43	4	1-8	0-2	
	BLACKHALL	fine sandy loam	0.2	7	15-35		
	EVANSTON	loam	0.37	8	2-8		
	CRAGO	gravelly-loam	0.2	4	0-2		
MT218	SHADOW	stony-loam	0.1	3	25-60		
(2.4 %)	MACFARLANE	very stony-loam	0.05	18	25-50		
	GARLET	stony-loam	0.2	4	25-60		
	PEELER	stony-sandy loam	0.17	20	25-60		
	COWOOD	very channery-loam	0.15	4	15-60		
	CHEADLE	channery-loam	0.2	4	15-60		
	GARLET	channery-loam	0.2	4	25-60		
	SEBUD	stony-loam	0.2	4	15-45		
	SHADOW	stony-loam	0.1	3	25-60		
	WOROCK	stony-loam	0.24	18	15-55		
MT488	MIDWAY	silty clay loam	0.43	3	15-45	2-4	
(2.2 %)	TRAVESSILLA FAMILY	silt loam	0.32	2	15-70		
	MCRAE	loam	0.37	5	25-35	0-2	
	BOWBAC	loam	0.37	5	8-15		
	LISMAS FAMILY	clay	0.37	2	8-15	0-8	
	SHINGLE	loam	0.32	4	15-45	0-2	
	RENTSAC	loam	0.32	7	25-40		
	ALLENTINE	clay loam	0.37	10	2-4		
	TOLUCA	clay loam	0.32	5	4-8	0-2	
	TRAVESSILLA FAMILY	silt loam	0.32	2	4-8		
	CUSHMAN	loam	0.37	7	25-35	0-2	
	HAVERSON	silty clay loam	0.28	6	0-4	0-8	
	NELSON	fine sandy loam	0.2	9	15-30	0-2	
MT175	DONEY	loam	0.37	4	8-15	0-2	
(2.1 %)	DONEY	loam	0.37	4	8-70	0-2	
	WAYDEN	silty clay loam	0.37	6	8-35	0-4	
	SHAAK	clay loam	0.37	6	2-15		
	SHAAK	clay loam	0.37	6	1-8		
	EVANSTON	loam	0.37	8	4-8		
	FARNUF FAMILY	loam	0.32	11	2-15		
	REEDER FAMILY	loam	0.32	5	3-15		
	DAST	sandy loam	0.2	3	8-15		
	KORCHEA FAMILY	loam	0.37	7	0-4		
	DAST	sandy loam	0.2	3	25-50		
MT550	SWEETGRASS	cobbly-	0.17	4	0-4		
(2.1 %)	HILGER	cobbly-loam	0.2	5	2-4		
	FAIRFIELD	gravelly-clay	0.17	7	2-4		
	MARTINSDALE	loam	0.37	6	2-4		
	HILGER	stony-loam	0.15	5	2-25		
	WORK	clay loam	0.32	6	2-8		
	TURNER	loam	0.37	7	2-4		

Note: Only the top 15 Map Units based on total acreage are included (% in parnthesis). This represents 48% of the soils in the study area.

EXHIBIT A-3

SOIL SERIES CHARACTERISTICS FOR BILLINGS RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
	BEAVERTON	gravelly-loam	0.2	7	2-8		
	BIG TIMBER	clay loam	0.32	6	8-15	0-2	
	CASTNER	stony-loam	0.2	6	2-25		

Note: Only the top 15 Map Units based on total acreage are included (% in parnthesis). This represents 48% of the soils in the study area.

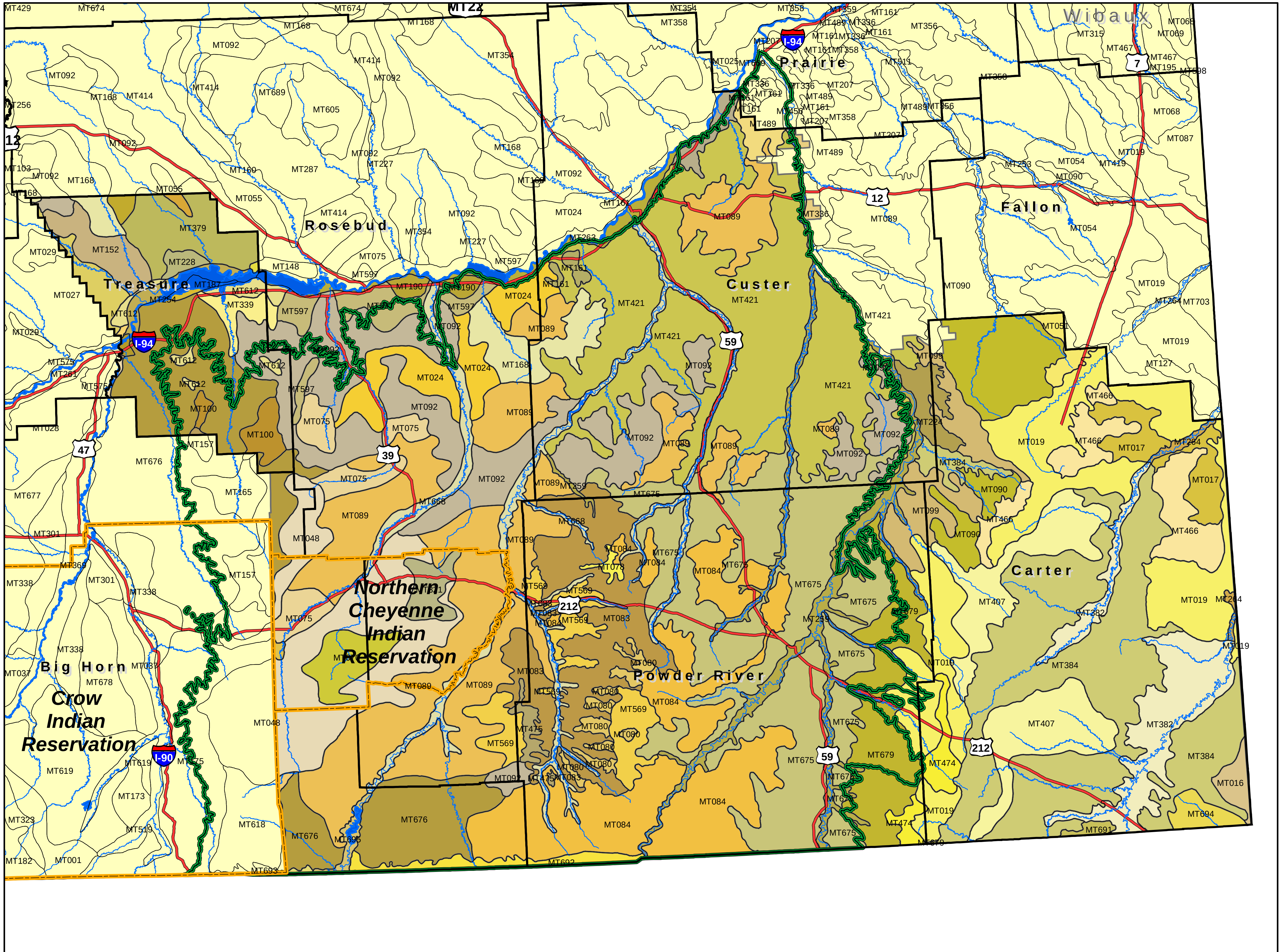
EXHIBIT A-3

SOIL SERIES CHARACTERISTICS FOR BILLINGS RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
MT167	TRAVESSILLA FAMILY	fine sandy loam	0.2	2	8-35		
(2.0 %)	DELPOINT	loam	0.37	3	8-15	0-4	
	CABBART	loam	0.37	3	8-35	0-4	
	RENTSAC	channery-loam	0.2	7	8-35		
	MARMARTH	loam	0.37	7	4-15		
	YAWDIM	clay loam	0.37	3	8-35		
	CAMBETH	silt loam	0.37	6	4-15		
	TANNA	clay loam	0.37	6	4-15		
	DELPOINT	loam	0.37	3	4-8	0-4	
	FLOWEREE	silty clay loam	0.32	6	0-4	0-2	
	EVANSTON	loam	0.37	8	4-8		
MT680	YAWDIM	silty clay	0.32	3	4-15		
(2.0 %)	ORINOCO	silty clay	0.28	7	4-15		
	AMHERST	clay loam	0.32	5	1-15		
	GERDRUM	clay loam	0.43	4	1-6	0-2	
	ETHRIDGE	clay loam	0.37	6	2-8		
	ZATOVILLE	silty clay loam	0.37	3	1-6	0-2	
	HARLEM	silty clay	0.32	10	0-2	2-4	
	TEIGEN	silty clay loam	0.37	4	1-6		
	WEINGART	silty clay loam	0.43	7	1-8	0-2	10-20
	AMHERST	clay loam	0.32	5	15-25		
	JULIN	silty clay loam	0.37	7	4-10		
	VOLBORG	silty clay	0.32	3	4-25	0-4	
	CRAGO	gravely-loam	0.2	4	15-35		

Note: Only the top 15 Map Units based on total acreage are included (% in parnthesis). This represents 48% of the soils in the study area.

Exhibit A-4: STATSGO Soils Types Powder River RMP Area

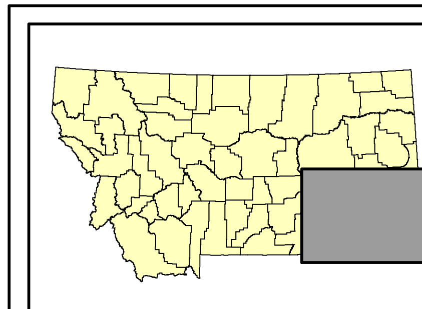


Legend

- Highways
- Rivers
- Powder River Geologic Basin Boundary
- Native American Reservations

Map Unit

MT016	MT148	MT407
MT017	MT152	MT414
MT019	MT157	MT421
MT024	MT161	MT456
MT027	MT168	MT466
MT029	MT175	MT474
MT048	MT187	MT475
MT051	MT190	MT489
MT054	MT224	MT569
MT055	MT228	MT575
MT070	MT254	MT597
MT075	MT259	MT612
MT078	MT261	MT618
MT080	MT263	MT668
MT083	MT264	MT669
MT084	MT321	MT675
MT089	MT336	MT676
MT090	MT339	MT679
MT092	MT369	MT691
MT099	MT379	MT692
MT100	MT382	MT693
MT127	MT384	MT694
		MT695



Location Map

Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

1:980,000

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.

EXHIBIT A-5

AREAL EXTENT OF SOIL MAP UNITS FOR POWDER RIVER RMA

STATSGO Map Unit	Acres	% Area	STATSGO Map Unit	Acres	% Area
MT016	21,332	0.25	MT259	173,933	2.03
MT017	78,323	0.91	MT261	3,146	0.04
MT019	459,121	5.36	MT263	47,424	0.55
MT024	129,347	1.51	MT264	10,938	0.13
MT027	29,864	0.35	MT321	35,383	0.41
MT029	565	0.01	MT336	5,762	0.07
MT048	304,837	3.56	MT339	28,331	0.33
MT051	21,144	0.25	MT369	2,414	0.03
MT054	2	<0.01	MT379	97,192	1.14
MT055	3,927	0.05	MT382	200,503	2.34
MT070	56,522	0.66	MT384	677,263	7.91
MT075	95,847	1.12	MT407	253,541	2.96
MT078	6,969	0.08	MT414	7,787	0.09
MT080	38,170	0.45	MT421	829,387	9.69
MT083	300,378	3.51	MT456	4,780	0.06
MT084	493,159	5.76	MT466	136,554	1.60
MT089	827,152	9.66	MT474	42,375	0.49
MT090	183,942	2.15	MT475	16,537	0.19
MT092	552,851	6.46	MT489	17,571	0.21
MT099	116,567	1.36	MT569	116,568	1.36
MT100	30,892	0.36	MT575	1,160	0.01
MT127	6	<0.01	MT597	72,598	0.85
MT148	1,072	0.01	MT612	30,042	0.35
MT152	54,694	0.64	MT618	3,515	0.04
MT157	1,109	0.01	MT668	211,006	2.46
MT161	10,319	0.12	MT669	22,214	0.26
MT168	103,294	1.21	MT675	758,425	8.86
MT175	2,526	0.03	MT676	445,328	5.20
MT187	9,089	0.11	MT679	189,351	2.21
MT190	19,800	0.23	MT691	7,403	0.09
MT224	38,201	0.45	MT692	36,589	0.43
MT228	11,675	0.14	MT693	1,971	0.02
MT254	30,577	0.36	MT694	26,102	0.30
			MT695	14,472	0.17

* Acreages are approximate - taken from 1:250,000 STATSGO Maps

EXHIBIT A-6
SOIL SERIES CHARACTERISTICS FOR POWDER RIVER RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
MT421	CAMBETH	silt loam	0.37	6	4-25		
(9.7 %)	MEGONOT	silty clay loam	0.37	5	4-15		
	MANNING	loam	0.32	5	8-15		
	CABBART	loam	0.37	3	15-45	0-4	
	CREED	loam	0.43	6	0-8	0-4	
	YAMAC	loam	0.37	5	0-15		
	GERDRUM	silty clay loam	0.43	4	0-8	0-2	
	ABOR	silty clay	0.37	6	15-25	0-4	
	KOBAR	silty clay loam	0.37	6	0-8	0-2	1-5
	DAVIDELL	silty clay loam	0.32	7	0-4		
	MARVAN	silty clay	0.37	4	0-8	0-4	0-4
MT089	CABBART	loam	0.37	3	15-70	0-4	
(9.7 %)	BIRNEY	channery-loam	0.2	5	25-70	0-2	
	YAMAC	loam	0.37	5	15-25		
	KIRBY	channery-loam	0.17	4	25-70	0-2	
	BIRNEY	channery-loam	0.2	5	4-25	0-2	
	YAMAC	loam	0.37	5	2-15		
	KOBAR	silty clay loam	0.37	6	0-8	0-2	1-5
	KOBAR	silty clay loam	0.37	6	2-15	0-2	1-5
	YAMAC	loam	0.37	5	2-8		
	YAWDIM	silty clay loam	0.37	3	8-70		
	GERDRUM	silty clay loam	0.43	4	0-8	0-2	
	DELPOINT	loam	0.37	3	15-25		
	DELPOINT	loam	0.37	3	25-70	0-4	
	BUSBY	fine sandy loam	0.2	4	8-25		
MT675	YAWDIM	clay loam	0.37	3	8-70		
(8.8 %)	CABBART	silt loam	0.37	3	15-75	0-4	
	THURLOW	silty clay loam	0.32	4	2-15		
	HYDRO	silty clay loam	0.32	7	0-15		
	CABBART	silt loam	0.37	3	8-15	0-4	
	REMMIT	fine sandy loam	0.24	12	4-25		
	CUSHMAN	silt loam	0.37	7	0-15	0-2	
	FLEAK	fine sandy loam	0.2	3	8-45		
	KEISER	silty clay loam	0.28	3	2-8		
	HAVRE	silty clay loam	0.32	8	0-4	0-2	
MT384	MARVAN	silty clay	0.37	4	0-8	0-4	0-4
(7.9 %)	NELDORE	clay	0.32	3	4-15	0-2	
	BASCOVY	clay	0.37	6	2-15	2-4	1-5
	GERDRUM	clay loam	0.43	4	0-8	0-2	
	VANDA	silty clay loam	0.43	4	0-8	2-8	20-30
	ORINOCO	silty clay loam	0.32	7	2-15		
	YAWDIM	silty clay loam	0.37	3	4-15		
	PINELLI	silty clay loam	0.37	3	2-8		
	VOLBORG	clay	0.32	3	4-45	0-4	
	CREED	loam	0.43	6	2-8	0-4	
	HAVRE	loam	0.37	8	0-2	0-2	

Note: Only the top 16 Map Units based on total acreage are included (% in parenthesis). This represents 80% of the soils in the study area. Map Units are presented in decending areal coverage.

EXHIBIT A-6
SOIL SERIES CHARACTERISTICS FOR POWDER RIVER RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
MT092	CABBART	loam	0.37	3	8-70	0-4	
(6.5 %)	DELPOINT	loam	0.37	3	15-25	0-4	
	YAMAC	loam	0.37	5	2-8		
	YAWDIM	silty clay loam	0.37	3	8-70		
	YAMAC	loam	0.37	5	4-15		
	BUSBY	fine sandy loam	0.2	4	8-25		
	DELPOINT	loam	0.37	3	4-15	0-4	
	ABOR	silty clay	0.37	6	8-25	0-4	
	GERDRUM	clay loam	0.43	4	2-8	0-2	
	DAVIDELL	loam	0.37	7	2-8		
	KOBAR	silty clay loam	0.37	6	0-15	0-2	1-5
	BUSBY	fine sandy loam	0.2	4	2-15		
	HAVRE	loam	0.37	8	0-2	0-2	
MT084	CABBA	silt loam	0.37	3	15-50	0-4	
(5.8 %)	RINGLING	slaty-loam	0.17	5	5-50		
	YAWDIM	clay loam	0.37	3	8-70		
	CABBART	silt loam	0.37	3	15-75	0-4	
	CABBART	silt loam	0.37	3	4-15	0-4	
	RELAN	loam	0.37	13	2-30		
	CUSHMAN	silt loam	0.37	7	2-8	0-2	
	KOBAR	silty clay loam	0.37	6	4-8	0-2	1-5
	KOBAR	silty clay loam	0.37	6	0-4	0-2	1-5
	THURLOW	silty clay loam	0.32	4	0-15		
MT019	ASSINNIBOINE	sandy clay loam	0.32	6	2-8		
(5.4 %)	PRING	sandy loam	0.2	10	2-8		
	ARCHIN	loam	0.43	12	2-8	0-2	
	EVANSTON	loam	0.37	8	2-8		
	YAMAC	loam	0.37	5	2-8		
	TWILIGHT	fine sandy loam	0.2	4	2-15		
	HAVRE	loam	0.37	8	0-2	0-2	
	DELPOINT	loam	0.37	3	8-15	0-4	
	FLEAK	loamy fine sand	0.17	3	15-50		
	GERDRUM	clay loam	0.43	4	0-8	0-2	
	BUSBY	fine sandy loam	0.2	4	2-15		
	CABBART	silt loam	0.37	3	8-15	0-4	
	BLACKHALL	fine sandy loam	0.2	7	8-15		
	BANKS	loamy fine sand	0.17	4	0-4		
	RHAME	fine sandy loam	0.2	8	3-9		
MT676	YAWDIM	silty clay loam	0.37	3	8-35		
(5.2 %)	DELPOINT	loam	0.37	3	15-35	0-4	
	DELPOINT	loam	0.37	3	8-15	0-4	
	THURLOW	silty clay loam	0.32	4	0-8		
	MCRAE	loam	0.37	5	1-8	0-2	
	DELPOINT FAMILY	stony-loam	0.24	2	15-70		
	FORELLE	loam	0.37	4	8-15		
	DAST	fine sandy loam	0.2	3	2-15		
	HARLEM	silty clay loam	0.37	10	0-4	2-4	
	ABOR	clay	0.37	6	0-15	0-4	
	VANDA	clay	0.37	4	1-8	2-8	20-30
	GERDRUM	clay	0.37	4	0-8	0-2	
	VANDA FAMILY	clay loam	0.37	6	0-4	8-16	20-30
	TRAVESSILLA FAMILY	loam	0.32	2	2-15		

Note: Only the top 16 Map Units based on total acreage are included (% in parenthesis). This represents 80% of the soils in the study area. Map Units are presented in decending areal coverage.

EXHIBIT A-6
SOIL SERIES CHARACTERISTICS FOR POWDER RIVER RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
MT048	BITTON	channery-loam	0.24	11	25-70	0-2	
(3.6 %)	CABBA	loam	0.37	3	8-70	0-4	
	SHAMBO	loam	0.37	5	0-8		
	DONEY	loam	0.37	4	15-70	0-2	
	DONEY	loam	0.37	4	2-35	0-2	
	SHAMBO	loam	0.37	5	8-15		
	RINGLING	channery-loam	0.17	5	3-70		
	SAGEDALE	silty clay loam	0.37	4	8-25		
	WAYDEN	silty clay loam	0.37	6	8-70	0-4	
	SAVAGE	silty clay loam	0.37	6	2-8		
	HAVRE	loam	0.37	8	0-2	0-2	
MT083	CABBA	silt loam	0.37	3	15-50	0-4	
(3.5 %)	RINGLING	slaty-loam	0.17	5	6-50		
	YAWDIM	clay loam	0.37	3	8-70		
	FARLAND	silt loam	0.37	4	0-8		
	CABBART	silt loam	0.37	3	8-75	0-4	
	HAVRELON	silt loam	0.37	13	4-6		
MT407	MOYERSON	silty clay loam	0.32	4	4-50	0-4	
(3.0 %)	ORINOCO	silty clay loam	0.32	7	2-15		
	YAWDIM	silty clay loam	0.37	3	4-15		
	PINELLI	loam	0.32	3	2-8		
	MARVAN	silty clay	0.37	4	0-8	0-4	0-4
	GERDRUM	clay loam	0.43	4	2-8	0-2	
	HAVRE	loam	0.37	8	0-2	0-2	
	VANDA	silty clay loam	0.43	4	0-2	2-8	20-30
MT668	YAMAC	loam	0.37	5	0-8		
(2.5 %)	HAVRE	silty clay loam	0.32	8	0-2	0-2	
	BIRNEY	channery-loam	0.2	5	15-35	0-2	
	KOBAR	silty clay loam	0.37	6	0-8	0-2	1-5
	GERDRUM	clay loam	0.43	4	2-8	0-2	
	HAVRE	silty clay loam	0.32	8	0-2	8-16	0-4
MT382	MARVAN	silty clay	0.37	4	0-8	0-4	0-4
(2.3 %)	GERDRUM	clay loam	0.43	4	0-8	0-2	
	VANDA	silty clay loam	0.43	4	0-8	2-8	20-30
	ABSHER	clay	0.37	5	0-8	4-8	1-5
	HARLEM	silty clay loam	0.37	10	0-2	0-4	0-4
	FORELLE	loam	0.37	4	2-8		
	BICKERDYKE	clay	0.32	4	0-2	0-2	
	HAVRE	loam	0.37	8	0-2	0-2	
	CREED	loam	0.43	6	2-8	0-4	
	NELDORE	clay	0.32	3	4-15	0-2	
	BASCOVY	clay	0.37	6	4-15	2-4	1-5
	TEIGEN	silty clay loam	0.37	4	0-4		
MT679	YAWDIM	clay loam	0.37	3	8-70		
(2.2 %)	HESPER	silty clay loam	0.37	2	0-15		
	CABBART	silt loam	0.37	3	15-75	0-4	
	CABBART	silt loam	0.37	3	8-15	0-4	
	REMMIT	fine sandy loam	0.24	12	4-25		
	GERDRUM	silt loam	0.49	4	0-8	0-2	
	FLEAK	fine sandy loam	0.2	3	8-45		
	FORELLE	silt loam	0.37	4	2-8		
	HAVRE	silt loam	0.37	8	0-4	0-2	

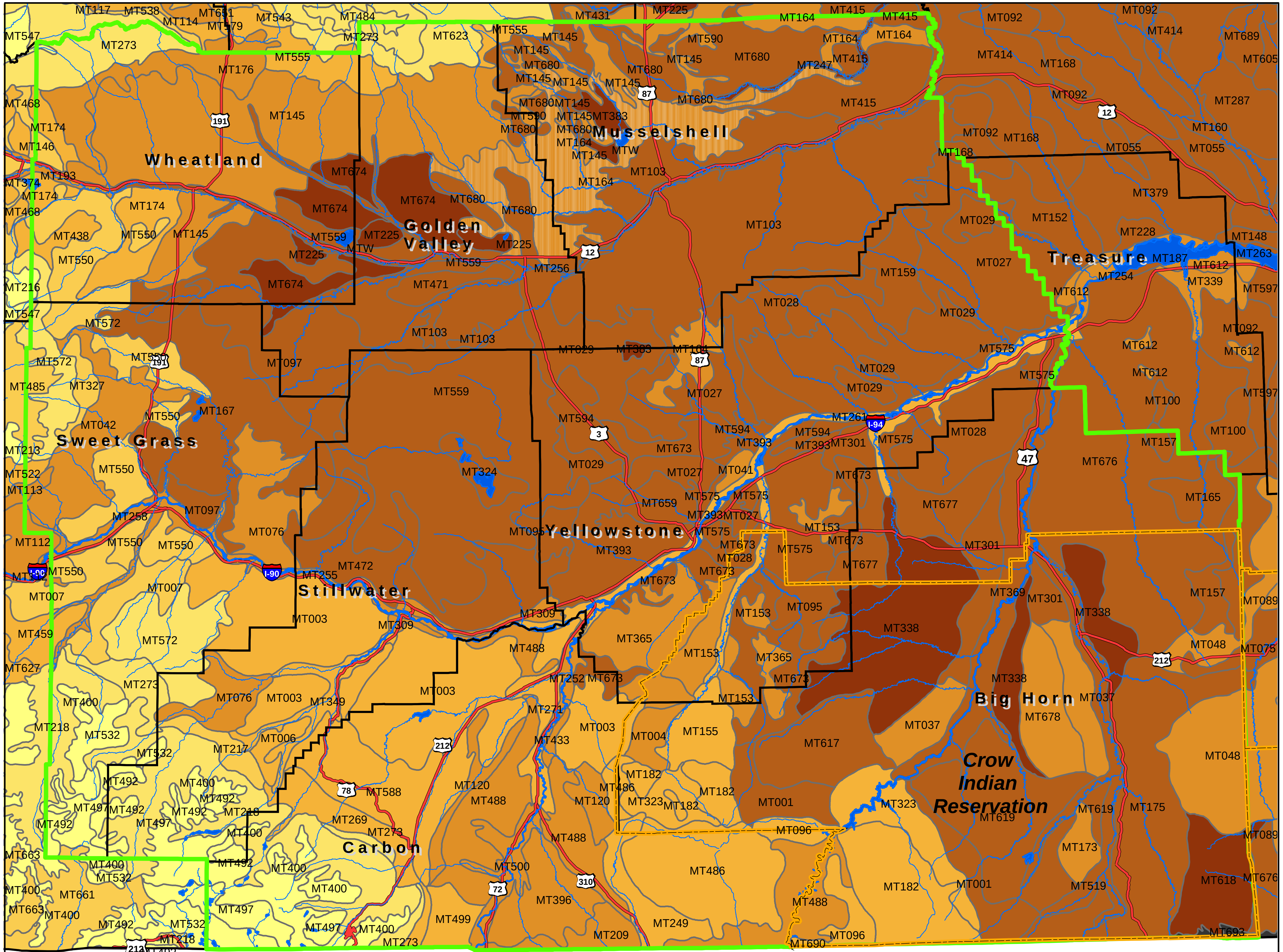
Note: Only the top 16 Map Units based on total acreage are included (% in parenthesis). This represents 80% of the soils in the study area. Map Units are presented in decending areal coverage.

EXHIBIT A-6
SOIL SERIES CHARACTERISTICS FOR POWDER RIVER RMA

STATSGO Map Unit	Soil Series	Surface Texture	K-factor	Depth (in)	Slope (%)	Salinity (mmhos/cm)	SAR
MT090	CABBART	silt loam	0.37	3	2-15	0-4	
(2.2 %)	CAMBETH	silt loam	0.37	6	2-15		
	CABBART	silt loam	0.37	3	15-45	0-4	
	BONFRI	loam	0.37	7	2-15		
	FORELLE	loam	0.37	4	2-8		
	GERDRUM	clay loam	0.43	4	2-8	0-2	
	PINELLI	silty clay loam	0.37	3	2-15		
	HAVRE	loam	0.37	8	0-2	0-2	
	TWILIGHT	fine sandy loam	0.2	4	2-15		
	PARCHIN	fine sandy loam	0.24	3	2-8	0-2	
	KIRBY	channery-loam	0.17	4	8-60	0-2	
	BLACKHALL	fine sandy loam	0.2	7	15-60		
MT259	HAVRE	silt loam	0.37	8	0-4	0-2	
(2.0 %)	HAVRE	silty clay	0.28	8	0-2	0-2	
	HANLY	fine sandy loam	0.17	5	0-4		
	GLENDIVE	fine sandy loam	0.2	5	0-2	0-4	
	HYDRO	silty clay loam	0.32	7	0-2		
	KOBAR	silty clay loam	0.37	6	0-2	0-2	1-5
	HAVRE	loam	0.37	8	0-4	8-16	0-4
	HAVRE	silty clay loam	0.32	8	0-4	0-2	

Note: Only the top 16 Map Units based on total acreage are included (% in parenthesis). This represents 80% of the soils in the study area. Map Units are presented in decending areal coverage.

Exhibit A-7: Mean K-Factor by STATSGO Map Unit Billings RMP Area



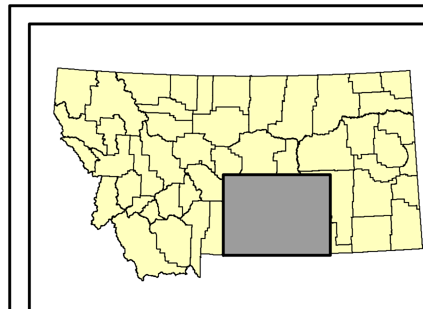
Legend

- Highways
- Rivers
- Native American Reservations

Mean K-FACTOR

- 0 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20
- 0.21 - 0.25
- 0.26 - 0.30
- 0.31 - 0.35
- 0.36 - 0.37
- 0.37 - 0.64

The mean K-factors for the different Soil Map Units are presented. The K-factor and slope are factors that are used in the estimation of soil erosion potential. Values above 0.37 are considered easily eroded. Resistant soils have a K-factor less than 0.37.



Location Map

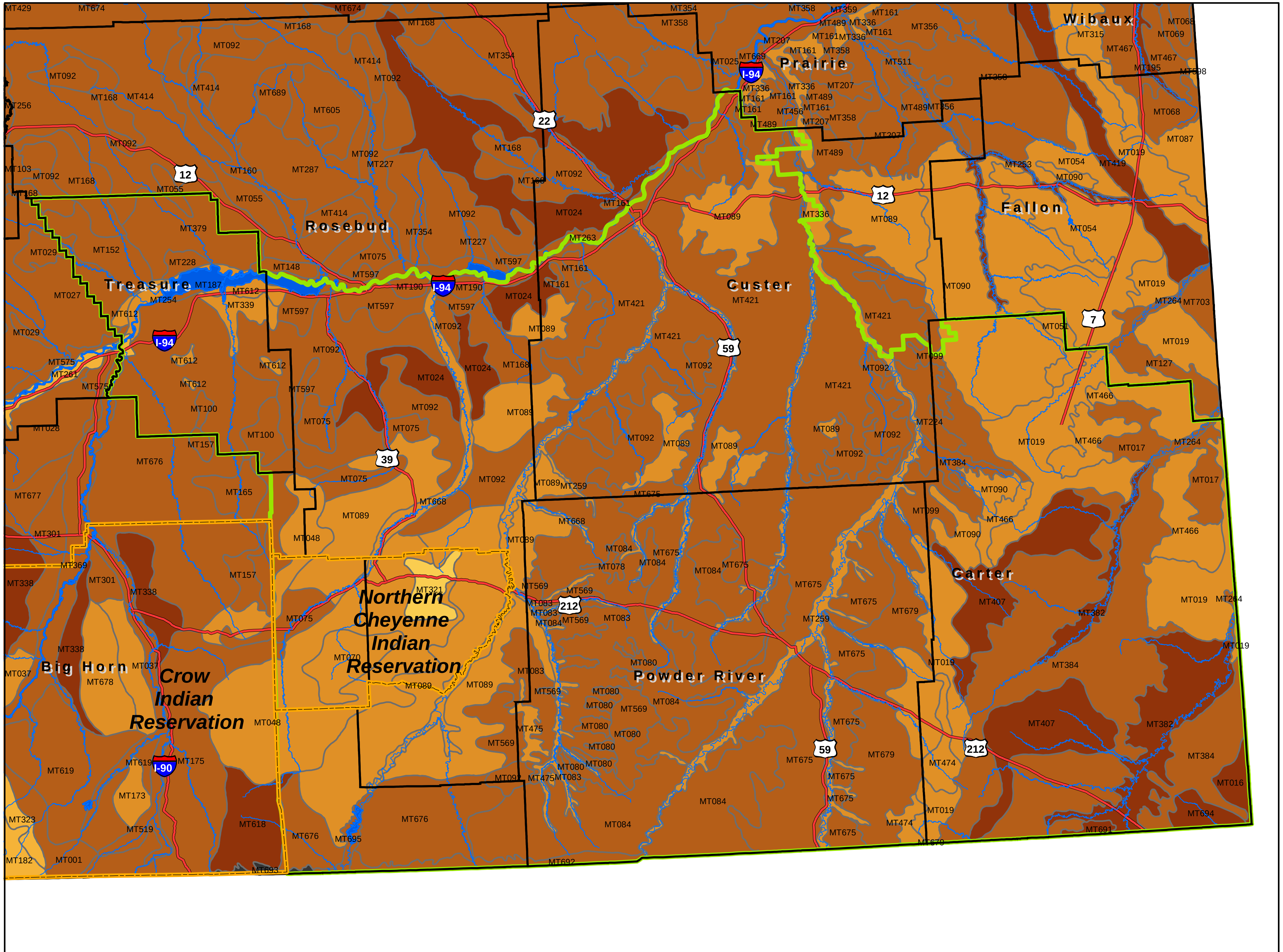
Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

N W E S

1:850,000

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.

Exhibit A-8: Mean K-Factor by STATSGO Map Unit Powder River RMP Area



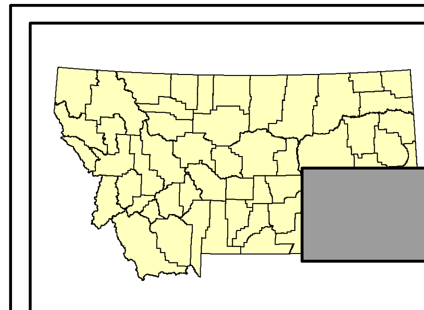
Legend

- Highways
- Rivers
- Native American Reservations

Mean K-FACTOR

- 0 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20
- 0.21 - 0.25
- 0.26 - 0.30
- 0.31 - 0.35
- 0.36 - 0.37
- 0.37 - 0.64

The mean K-factors for the different Soil Map Units are presented. The K-factor and slope are factors that are used in the estimation of soil erosion potential. Values above 0.37 are considered easily eroded. Resistant soils have a K-factor less than 0.37.



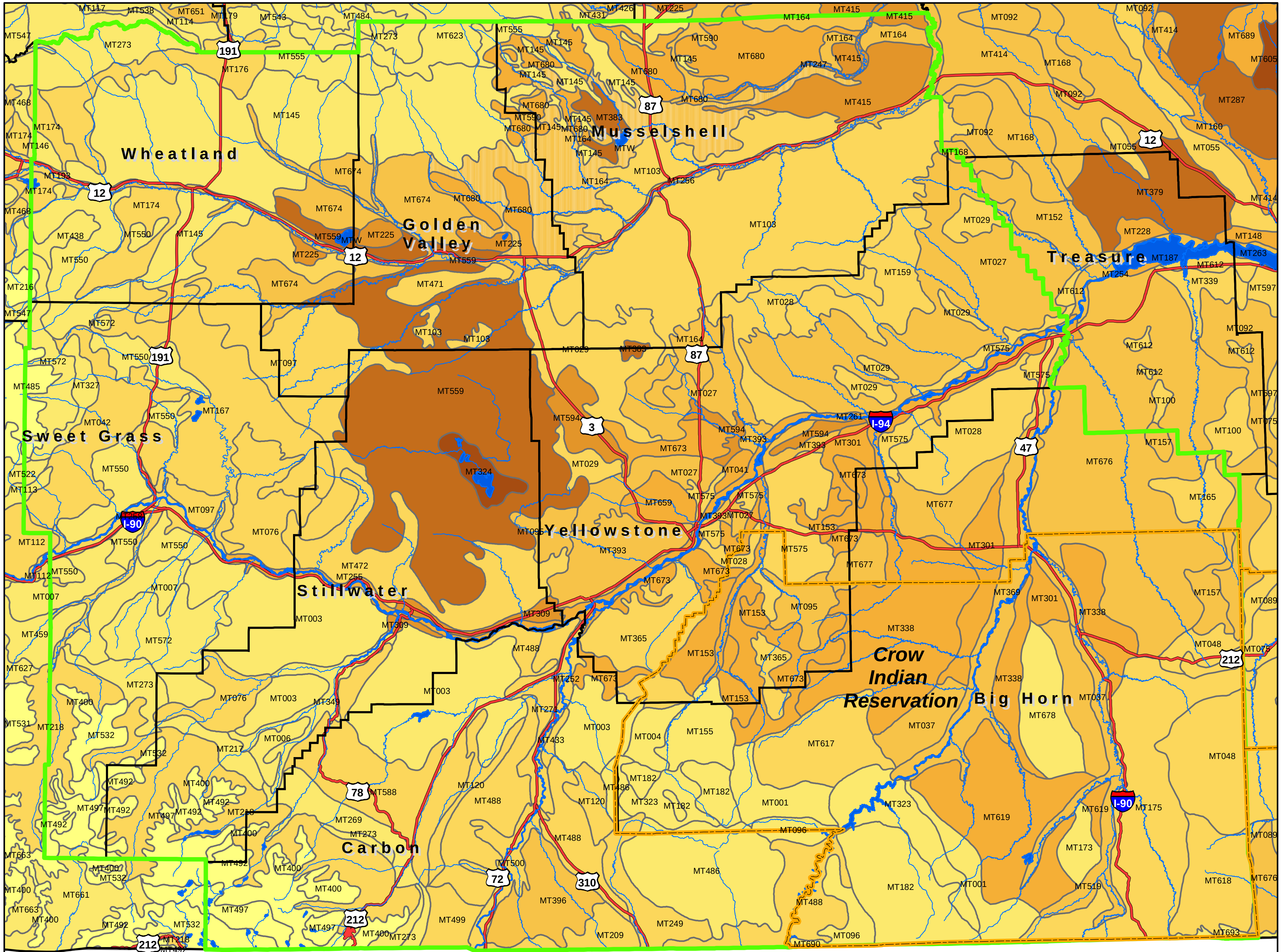
Location Map

Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

1:980,000

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.

Exhibit A-9: Mean Soil Salinity by STATSGO Map Unit Billings RMP Area



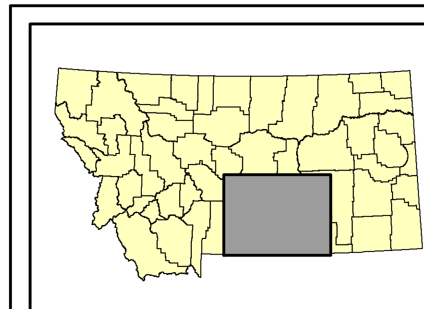
Legend

- Highways
- Rivers
- Billings RMP Area Boundary
- Native American Reservations

Mean Salinity (mmhos/cm)

- 0 - 1.59
- 1.60 - 3.19
- 3.20 - 4.79
- 4.80 - 6.39
- 6.40 - 7.99
- 8.00 - 9.59
- 9.60 - 11.19
- 11.20 - 12.79
- 12.80 - 14.39
- 14.40 - 16

Salinity is a measurement of the salt load on soils and affects crop water availablity. It is a measurement of the electrical conductivity (EC) of the soil. STATSGO provides a range of low and high values for salinity for soils. The mean of the high value of the range was used for this exhibit in order to present conservative values. Actual value ranges are presented in Exhibit A-3 (Billings) A-6 (PRB).



Location Map

Date Prepared: April 2, 2001

Prepared by: J. Patton

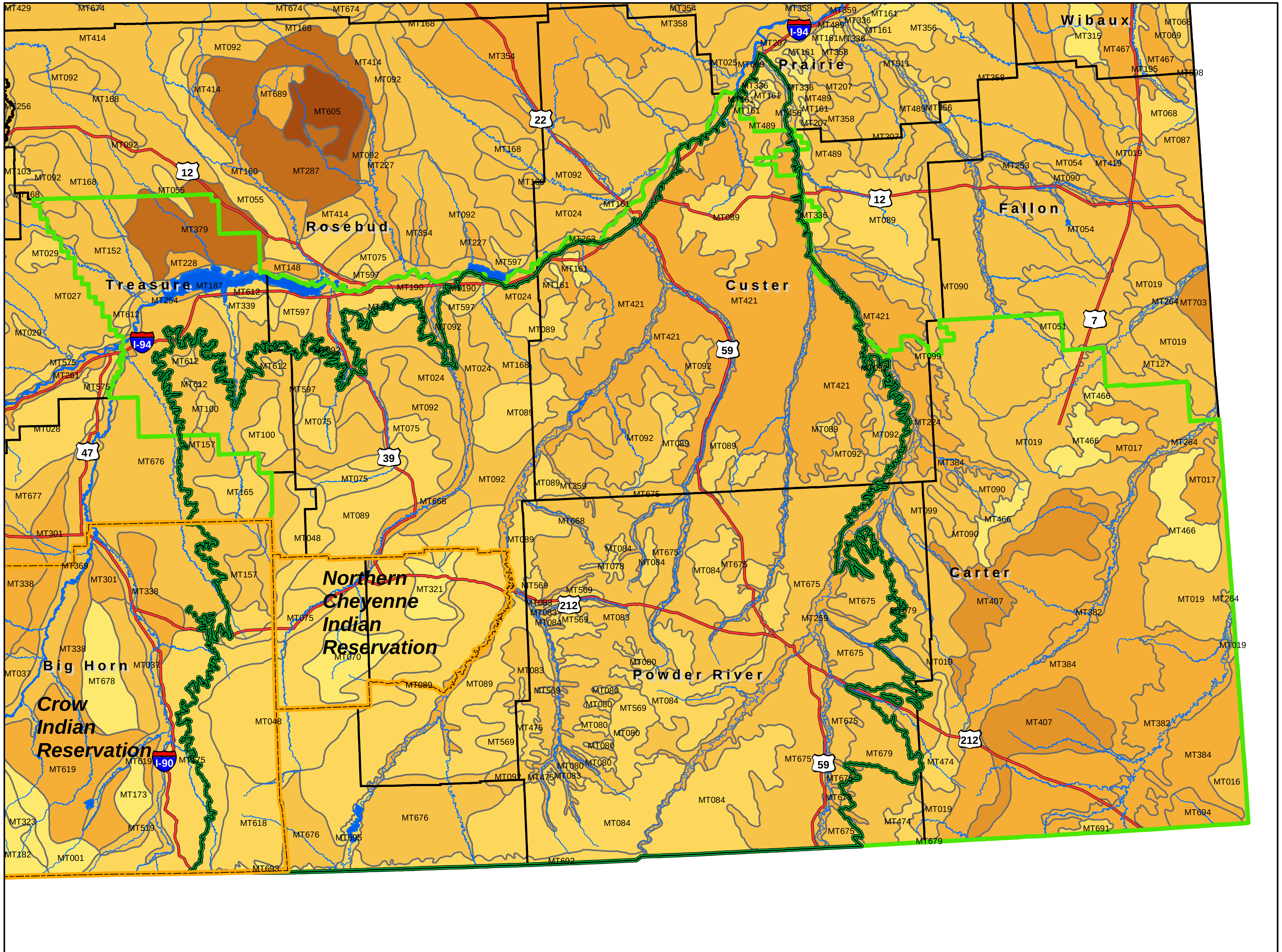
Project Mgr.: D. Arthur

1:850,000

DATA SOURCES

Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.

Exhibit A-10: Mean Soil Salinity by STATSGO Map Unit Powder River RMP Area



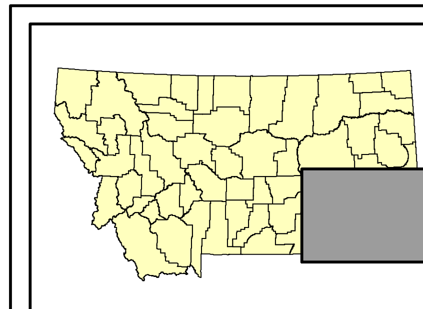
Legend

- Highways
- Rivers
- Native American Reservations
- Powder River RMP Area
- Powder River Geologic Basin Boundary

Mean Salinity (mmhos/cm)

- 0 - 1.59
- 1.60 - 3.19
- 3.20 - 4.79
- 4.80 - 6.39
- 6.40 - 7.99
- 8.00 - 9.59
- 9.60 - 11.19
- 11.20 - 12.79
- 12.80 - 14.39
- 14.40 - 16

Salinity is a measurement of the salt load on soils and affects crop water availablity. It is a measurement of the electrical conductivity (EC) of the soil. STATSGO provides a range of low and high values for salinity for soils. The mean of the high value of the range was used for this exhibit in order to present conservative values. Actual value ranges are presented in Exhibit A-3 (Billings) A-6 (PRB).



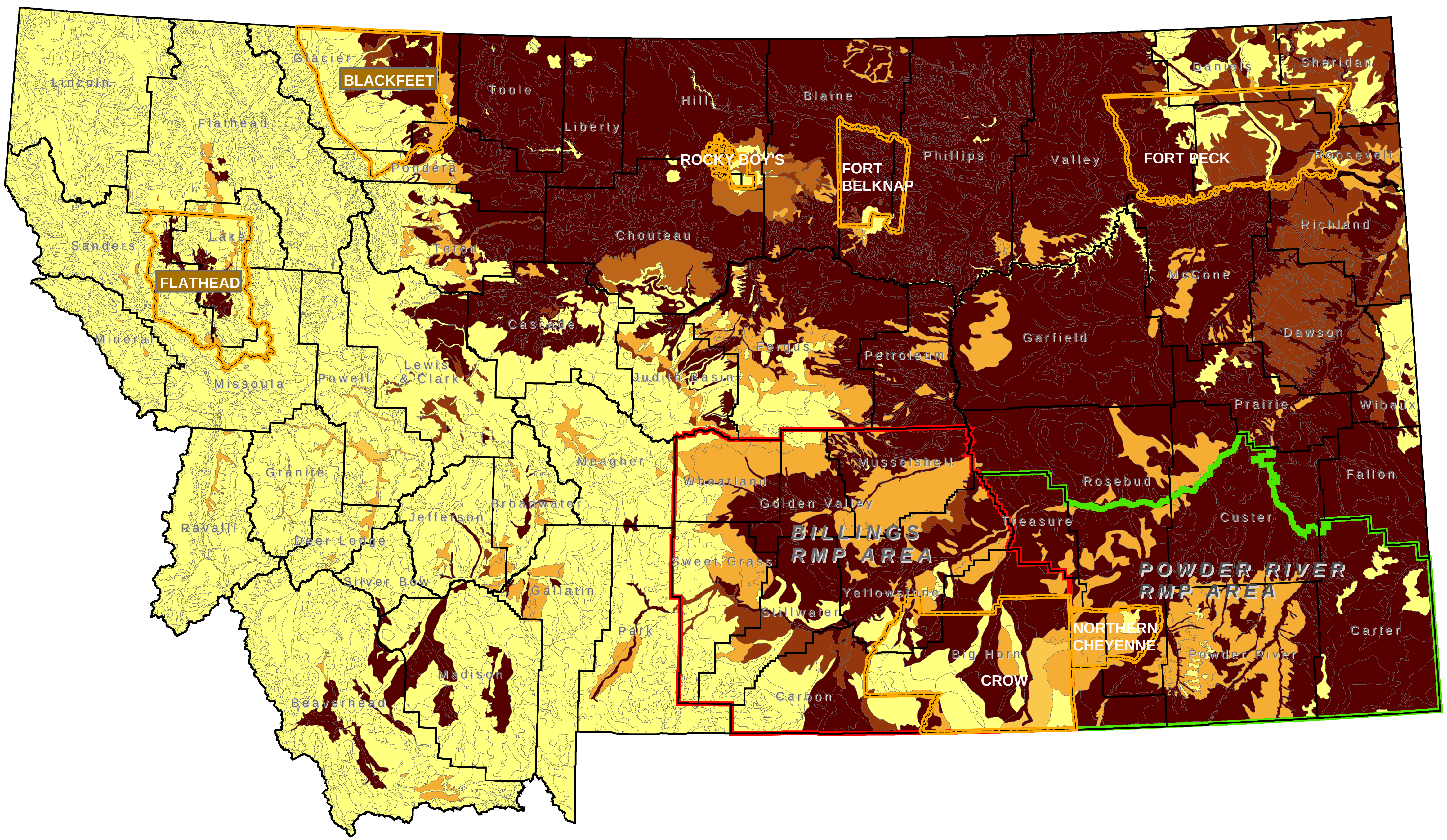
Location Map

Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

1:990,000

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.

Exhibit A-11: Statewide Maximum Soil SAR by STATSGO Map Unit



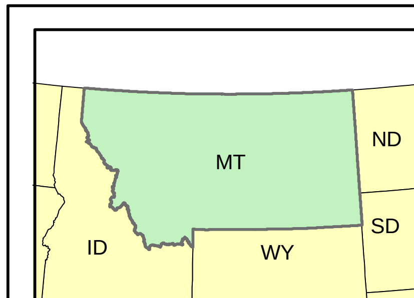
Legend

- Powder River RMP Area
- Billings RMP Area
- Native American Reservations

MAX SAR

- 0
- 0.01 - 0.9
- 1.00 - 1.99
- 2.00 - 2.99
- 3.00 - 3.99
- 4.00 - 4.99
- 5.00 - 5.99
- 6.00 - 6.99
- 7.00 - 7.99
- 8.00 - 8.99
- 9.00 - 9.99
- 10.00 - 10.99
- 11.00 - 11.99
- 12.00 - 200

The Sodium Absorption Ratio (SAR) is a measure of sodicity, and affects the infiltration rate of water. Usually, SAR values below 3.0 are not considered to be a threat to crops and native plants, however SAR values above 12.0 are considered sodic and may affect soils and vegetation. The STATSGO data for SAR is sparse and may not accurately represent all soils in a given Map Unit. Refer to Exhibits A-3 and A-6 for actual value ranges.



Location Map

Date Prepared: April 2, 2001
Prepared by: J. Patton
Project Mgr.: D. Arthur

N W E S

1:3,000,000

50 25 0 50 Miles
50,000 25,000 0 50,000 100,000 Meters

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Highways: 1:100,000 scale, roads, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana.
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana.
Soils: 1:250,000 scale, USDA NRCS, STATSGO Database for Montana.

APPENDIX B

SELECTED AG NOTES FROM MONTANA STATE UNIVERSITY EXTENSION SERVICE

http://scarab.msu.montana.edu/Agnotes

?? Ag Note No. 51: Some Guidelines for Irrigating With Saline Water

?? Ag Note No. 67: The Erosion Process How It Happens

?? Ag Note No. 71: Acceptable Irrigation Water Quality

?? Ag Note No. 72: Understanding Saline and Sodic Soils

?? Ag Note No. 73: Soil Quality and Water Quality Texture Salinity Sodium Water

?? Ag Note No. 116: Management of Saline and Sodic Soils Gypsum, Sulfur, and Other Myths

?? Ag Note No. 137: Salt Problems Common in Some Soils of Montana

?? Ag Note No. 146: Suitability of Water for Livestock

?? Ag Note No. 155: Some Guidelines For Irrigating With Saline Water

?? Ag Note No. 170: Soil Salinity Crop And Forage Tolerances

SOME GUIDELINES FOR IRRIGATING WITH SALINE WATER AGRONOMY NOTES NO. 51

http://scarab.msu.montana.edu/Agnotes/category_167.htm

The quality of water from Montana's rivers and streams generally decreases as the irrigation season progresses. Historic records indicate that sediment load is usually heaviest during the May and June snowmelt runoff periods and as the sediment load decreases and stream volumes decrease, the salt level of most rivers and streams increases. This is particularly true to the streams and rivers east of the Continental Divide. With that being the case, a few guidelines for irrigating with salty water might prove useful for irrigators -especially those using water from the Powder, Milk, Marias, Tiber, Musselshell, Tongue Rivers and secondary tributaries to the Missouri and Yellowstone Rivers.

Irrigating with saline (salty) water. The smaller rivers that supply most of the irrigation water for the eastern two-thirds of Montana are interesting -the saline and volume change dramatically during the year. Review of the historic water quality and flow records indicate several changes through the year. Knowledge of these changes may be of some value in attempting to "get the most" our of the available irrigation water.

?? Fill the profile as early as possible after the peak flood stage or as soon after harvest as possible, if you are harvesting forages (hay, alfalfa). The sediment and salinity levels tend to increase beginning early in the spring as runoff begins. Salinity level peaks and then starts to decrease as dilution takes over, while sediment continues to increase. During the high flow period salinity is low, but sediment is high. Sediment generally tends to start decreasing dramatically after the peak.

?? If at all possible, delay irrigation until after the peak flow period, as the flow level begins to drop. Salinity and sediment tend to be lower at this flow rate on the "down" or falling stage than the same stage on the "up" or rising level part of the cycle.

?? Some sediment in the water will help move the advancing wetting front across border-dike, graded border, basin, and furrow irrigated fine sandy loam soils.

Salinity (or salt load) is best determined by measuring the TDS (total dissolved solids) or EC (electrical conductivity). The TDS varies from as low as only a few hundred parts per million (or milligrams per liter), to as much as 2500 to 3000 parts per million (mg/l) during the lowest flow periods in some of the smaller streams of eastern Montana. The lowest TDS usually occurs when the river level has risen to its maximum and is then falling. When the river goes through rising and falling stages due to rain (especially thunderstorms), the TDS is usually lower at a given river level when the level is falling, rather than rising.

Irrigation strategies to reduce salt load. If possible, when irrigating in the spring and early in the irrigation season, fill the profile with water of low TDS/EC. The EC of the water will generally be between 0 and 9 mmhos/cm (equal to 9000 micromhos/cm). To convert this value to an approximate TDS (total dissolved solids), multiply the EC in mmhos/cm by 640. The result will be an approximate TDS in milligrams per liter. The soil will tend to concentrate salt during the irrigation season and thus have an EC greater than the irrigation water. In well-drained soils, the EC will be about the same all the way through the root zone, while on poorly drained soils, the EC will generally increase dramatically with depth. Young plants and seedlings are much more sensitive to EC of both the irrigation water and soil than established plants. Once the EC gets above about 2.4 mmhos/cm in the soil, plants will begin to show signs of stress -stress that looks just like drought.

Irrigation strategies to reduce salt injury to seedlings. On new plantings of alfalfa, grass, other legumes, small grains, corn, and sorghum, shorten the length of time or your sets early in the season, when plants are still small, and irrigate just a little more frequently. You'll pump just the same amount of water as before, but get a better stand, better early growth, and an increase of as much 25% in overall yield. In addition, the irrigation water will tend to have slightly less dissolved salt this time of the season.

Use of saline water for irrigation. The following is a summary of an article by J. D. Rhoades, soil scientist with the U.S. Salinity Lab in Riverside, CA. The article first appeared in the October 1984 issue of California Agriculture. Saline water, or water which is generally classified as having too much dissolved salt for irrigation, can often be used successfully without hazardous long-term effects on the crops or soils. However, certain conditions need to be met:

?? The soil being irrigated must be well-drained

?? Salt tolerant crops (established alfalfa, barley, sorghum, sudan grass, sordan) should be the primary crops grown

?? Rotations should be planned to provide for a sequence of progressively more salt tolerant crops

?? Salts should be leached out of the soil in the spring or winter

?? As the salinity of either the irrigation water or soil solution increases (with prolonged crop water use and through the irrigation season), the volume of irrigation water applied should be progressively increased.

As Rhoades points out, adoption of new crop and water management strategies can further facilitate the use of saline water for irrigation. One strategy is to substitute more saline water (later in the irrigation season) for good quality water to irrigate certain crops in the rotation or well-drained soils. Whatever salt buildup that might occur in the sol from irrigating with salty water can be reduced in the following winter or spring from rainfall or irrigation with low-salinity irrigation water.

Soils do not usually become excessively saline from use of saline water in a single irrigation season. It may even take several irrigation seasons to affect the level of salt in the soil solution. The maximum soil salinity in the root zone that results from continuous irrigation with saline water does not occur when salty water is used only a fraction of the time.

For purposes of comparison, Colorado River irrigation water has a TDS of about 900 ppm, while the rivers of central and eastern Montana generally ranges from about 750-1,500 ppm during the irrigation season. Drainage water TDS will usually be 3,500 to 4,500 ppm.

THE EROSION PROCESS HOW IT HAPPENS AGRONOMY NOTES NO. 67

http://scarab.msu.montana.edu/Agnotes/category_96.htm

Every time a raindrop hits a bare, unprotected soil surface, it is like a miniature version of a huge boulder being dropped from an airplane onto a pile of smaller rocks. The blasting action of falling rain both loosens some soil particles and packs others. Then it floats away some of the loosened particles.

Naturally, if the raindrop hits a piece of plant residue, expending its energy that way, the water from the raindrop just trickles down to the soil; no blasting and very little packing. Admittedly, there's still an opportunity for the raindrop -and many others like it -to float off some soil particles, but they don't usually go far or pick up much soil before they hit one of the many little dams created by residue and debris on the soil surface of fields where residue has been left after harvest.

Water Erosion—The Process

Sheet erosion is the process, when a uniform later of topsoil is skimmed from the surface by flow of water from either rainfall or melting snow. This is the least noticeable kind of erosion. The only time it gets noticed is when the eroded soil settles out in a low spot and silt, the soil particle most often moved by sheet erosion, at least partially buries emerging crops or other vegetation.

Rill erosion occurs when flow from rain or melting snow forms little streams as the water heads down hill, cutting small gullies as it goes. This is a more noticeable kind of erosion, but one which is quickly covered over again by the next tillage operation. Rill erosion can -and often does -occur for years without attracting attention from farm operators. However, it is a signal that this particular type of soil is quite easily eroded. The soil surface needs protection -either permanent cover or use of conserving practices such as conservation tillage -or long-term productivity will begin to diminish. And, research has clearly shown that it is no easy or short-term process to restore this productivity, especially on knolls, hilltops, and hillsides.

The most noticeable kind of erosion is where actual gullies are cut by flowing water. Gaps too wide and deep to cross with farm equipment can develop during extremely heavy rains. Generally, drastic measures are needed to solve this problem -permanent grass waterways, permanent cover crops.

The Wind Erosion Process—Montana's Major Concern

Wind can carry soil particles from unprotected soil, just as water can. Just like the dust in front of your truck or tractor tires and the dust behind you as you cross a field, turbulence similar to that occurs when wind starts sweeping across unprotected fields. When an air current gets a straining shot at a particle of soil, that particle can be lifted by the energy in the wind, perhaps dislodging some others as it becomes airborne. Fertilizers, herbicides, and insecticides, either chemically attached to the soil or free among the soil particles -can be moved right along with the soil materials.

Conservation tillage is probably more effecting in countering the action of wind erosion that it is in deterring water erosion. Even a rough soil surface helps break the velocity of air currents at ground level. Residue does an even more efficient job since the surface of stalks and stubble can't be lifted to knock loose others.

Naturally, different soil types and degrees of slope affect erosion potential of unprotected soil. In addition, soil moisture, previous crop, period of the year, and the general openness and position in the landscape all have a bearing on how much soil can be pried loose by water and wind.

Soil which has been loosened by freezing and thawing and wetting and drying action tends to be more easily eroded in the spring; that's when most rainfall occurs, also. Later in the season, after the soil has been packed by rainfall, it is usually less subject to erosion. This is also when crop cover is often present to protect the soil surface. Needless to say, conservation tillage practices -those which leave some crop residue on the soil surface during the non-cropping period, can help reduce erosion by wind and water -both by absorbing some of the energy and by slowing the movement of soil once it begins.

ACCEPTABLE IRRIGATION WATER QUALITY AGRONOMY NOTES NO. 71

http://scarab.msu.montana.edu/Agnotes/category_169.htm

NOTE: During the next month I will be presenting a series of four notes dealing with irrigation water management, irrigation water quality, and soil quality related to irrigation management. There is a water quality component to this series. Throughout the winter I will continue to concentrate efforts on several specific subjects and topics -a new one each month. If you have specific agronomy -related issues you wish to see addressed, please let me know. If I can't find the text resources, I will contact some of the other specialists or do a WEB search to see what I can find for you.....

Seasons Greetings -early.....

Irrigators could benefit by periodically sampling and testing their irrigation water. Although soil testing will provide a general guideline of the effect irrigation water might be having on soil quality, the chemistry of the soil will only reflect the chemical content of irrigation water after several cropping seasons. Irrigators should realize that groundwater quality can change with time and surface water quality changes seasonally; surface water tends to become more saline as stream flow declines. If an irrigator is going to sample water for testing, the sample should be collected after the well or supply has been pumped for some time and the sample should be placed in a clean container.

Table 1 provides a summary of the limitations that might be associated with irrigation water. The most important qualities to consider are the electrical conductivity (EC), which is a measure of the amount of dissolved salts; the pH, which is a measure of the acidity; and the adjusted sodium adsorption ratio (SAR), which is an index of the relationship between the concentration of sodium and calcium and magnesium. (Another measure of salinity is the total dissolved solids (TDS), which can be estimated from the EC by multiplying the EC value in mmhos/cm by 640).

Salinity generally has more of an adverse effect on the crop than on the soil being irrigated. Most crops have some degree of sensitivity to salt, because of the competition for water. In addition, some constituents of dissolved salt can sometimes be toxic to plants in high concentrations. Sodium, on the other hand, can have an adverse effect on soil permeability. Heavy-textured soils and sprinkler-irrigated soils have the greatest sensitivity to permeability hazard from sodium in irrigation water.

Irrigation water that is suitable for one soil may not be suitable for another soil. Sodium affects clayey soils more than it affects sandy soils. Soluble salts are leached from sandy soils more readily than they are leached from clayey soils.

Guidelines for interpretation of irrigation water quality:

Limitation	Acceptable	Increasing	Severe Problem
------------------Range of EC (mmhos/cm) -------------------			
salinity (affects crop growth)	<0.75	0.75-3.0	>3.0
-------------------Range of TDS (mg/l or ppm)---------------			
	<480	480-1920	>1920
--			
--------------------Range of EC (mmhos/cm) --------------------			
permeability (affects infiltration and drainage)	>0.5	0.2-0.5	<0.2
-------------------Range of TDS (mg/l or ppm)---------------			
	>320	130-320	<130
-------------------Range of SAR (adjusted)--------------------			
	<8	8-16	>16

Suggested range in irrigation water EC and SAR for different soils:

	EC Range (mmhos/cm)		**SAR Upper Limit**	
Soil Texture	**Flood**	**Sprinkler**	**Flood**	**Sprinkler**
Very coarse (sands, loamy sands)	0-4	0-5	18	24
Coarse (sandy loam)	0-3	0-4.5	12	15
Medium (loams, silt loams)	0.2-2.5	0-3	12	15
Medium fine (clay loam, sandy clay loam)	0.3-2.5	0.2-3	8	12
Fine (silty clay loam, clay, sandy clay, silty clay)	0.5-2	0.3-2.5	6	9

UNDERSTANDING SALINE AND SODIC SOILS
AGRONOMY NOTES NO. 72

http://scarab.msu.montana.edu/Agnotes/category_289.htm

Salinization of soils is common in Montana. Although salinization occurs naturally, without careful management of either irrigated and dryland soils, it is possible for salinization to increase. At present, more than 280,000 acres of land in Montana are characterized as sodium or salt-affected. Understanding saline and sodic soils, their causes and management will help land managers reduce their incidence in the future.

Where does salt come from? All waters and parent rock contain some salts. The amount of salt is dependent on several factors, the most important being the parent material, the conditions under which the soil formed, the drainage of the soil, and the predominant weather conditions. The term saline refers to more than just sodium or chloride. Such ions as magnesium, calcium, carbonate, bicarbonate, and sulfate can all contribute to salinity. As water evaporates from a soil surface or is used by plants, the salts in the water are left behind. This causes salt to accumulate in the soil. If this salt accumulation is not balanced or offset by downward leaching, due either to rainfall or irrigation, salinity will occur. If the predominant ion is sodium, then the soil can also be sodic.

Where do saline and sodic soils occur in Montana? The most common locations to find saline soils are in the eastern and central part of Montana and in poorly drained areas north of the Missouri River. Naturally saline soils are found along many stream terraces and bottoms, while saline seeps can be found throughout most of the glaciated plains region. Sodic soils are unlike saline soils, although they occur in many of the same locations and can form together. Sodic soils are most common in eastern and north central Montana and along irrigated flood plains of many rivers.

Saline soils contain excess soluble salts, which make it difficult for plants to take up water and nutrients. A saline soil (see Table 1) has an electrical conductivity (EC) more than four mmhos/cm. Saline soil causes spotty bare areas in a crop field, due to poor emergence. In severe cases, the soil will have a white residue at the surface. Irrigated saline soils can be improved by leaching and good drainage. Dryland saline seep areas can be reclaimed by planting deep-rooted perennials such as alfalfa, sweet clover, and grasses in the recharge areas.

Sodic soils contain excess exchangeable sodium; this sodium is not harmful to plants, but it does make fine-textured soil extremely impermeable to water and difficult for roots to penetrate. Sodic soils have an exchangeable sodium percentage (ESP) more than 15% or a sodium adsorption ratio (SAR) more than 12. Sodic soils generally occur as localized pan spots. The subsoil of sodic soils is usually very compact, moist, and sticky and is composed of soil columns with rounded caps. To improve sodic soils, the sodium must be replaced with calcium and the sodium leached from the soil. Hence, it is not possible to reclaim a sodic soil without good drainage. The sodium can be replaced by adding calcium in the form of gypsum or calcium chloride or by adding materials which will release the calcium already present (sulfur, sulfuric acid, organic matter).

Saline-sodic soils have both excess soluble salts and exchangeable sodium. To improve these soils, amendments and drainage are essential. Leaching a saline-sodic soil without amendments will result in a sodic soil and may worsen the soil structure.

TABLE 1
CONDITIONS OF SALINE, SODIC, AND SALINE-SODIC SOILS

Soil condition	EC (mmhos/cm)	ESP (%)	SAR
Saline	>4	0-15	0-12
Sodic	0-4	>15	>12
Saline-sodic	>4	>15	>12
Non saline, non sodic	0-4	0-15	0-12

Things to remember: saline soils -the problem is lack of available water to plants and toxicity; the solution is leaching and improved drainage. Sodic soils -the problem is poor soil structure, drainage, and impermeability; the solution is addition of soil amendments and improved drainage. Saline-sodic soils -the problem is lack of available water, and poor drainage; the solution is addition of amendments, leaching, and improved drainage.

How do I know if the problem is there? Often the problem is obvious. The presence of a permanent or seasonal high water table will often be a sign of saline or sodic soils. Poorly drained potholes in glacial landscapes often have localized areas that have temporary high water tables. Excess soluble salts will often crystallize on the surface of fallow fields. Thick continuous crusts form in saline seeps. Thin patchy salt crusts will form under clods or on the shady side of clods where marginal salt problems are found. Patterns of growth in cropped fields will be poor, spotty stand establishment. Saline soils tend to inhibit germination and emergence of cereal grains. Under severe salt stress, herbaceous crops appear bluish-green; leaf tip burn and die-off of older leaves in cereal grains can result from salinity or related drought stress.

SOIL QUALITY AND WATER QUALITY TEXTURE SALINITY SODIUM WATER—AGRONOMY NOTES NO. 73

http://scarab.msu.montana.edu/Agnotes/category_290.htm

Every once in a while someone calls me with a question that is worth either repeating, sharing, or expanding on. One example is the following. I received a call from a lady asking me how much water she should be irrigating with. Well.... the answer is sort of long and drawn out and complicated -you know, that depends on a lot of different factors. But, before we finished our conversation, I offered her what turned out to be one good piece of advice. The question turned into an answer like the following: The available water-holding capacity of a soil is a function of the texture. How much water the soil can actually hold (or how much of the water which is being applied) depends on both the water holding capacity and just how dry the soil is when the water is added. As an example, the following table illustrates the Available Water Holding Capacity of Soils. This is the amount of water that would and could be made available to plants after the soil had been irrigated:

Soil Texture	Inches of Water Per Foot of Moist Soil
Sands and fine sands	0.75
Very fine sands, loamy sand	1.00
Sandy loam	1.50
Loam	1.90
Silt loam, silt	2.20
Silty clay loam	1.90
Clay loam, sandy clay loam	1.70

She then started asking questions about all the terms that appeared on her water test report. Like, what is EC, SAR, ESP, and Conductivity. So.....

Conductivity (also referred to as EC, electrical conductivity) -an index of the dissolved solids concentration. Usually presented in either micromhos/cm or millimhos/cm. Low salinity water is water with a conductivity between 0 and 250 micromhos/cm (0.25 mmhos/cm). Low salinity water can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop, as long as there is good drainage. Some leaching is required (rainfall will generally be enough), but this occurs under normal irrigation practices.

Medium salinity water has a conductivity between 250 and 750 micromhos/cm (0.25-0.75 mmhos/cm). This water can be used if a moderate amount of leaching occurs as a result of the combined effects of irrigation and rainfall. Plants with moderate salt tolerance can be grown -grasses do well.

High salinity water has a conductivity between 750 and 2250 micromhos/cm (0.75-2.25 mmhos/cm). This water should not be used on any soils with restricted drainage or where excessive water is not available for continuous leaching. Special management for salinity control is necessary with this water.

Needless to say, water with salinity above 2250 micromhos/cm is very saline and should not be used for irrigation. This water is only occasionally suitable, where excess leaching with good-quality water will follow. As for SAR -the Sodium Adsorption Ratio -this is (generally speaking) the ratio of the amount of sodium to the amount of calcium and magnesium. Ideally, this number should be small. Low-Sodium water is water with an SAR less than 10. This water can be used for irrigation on almost all soils with little danger of development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees may accumulate injurious concentrations of sodium.

Medium Sodium water is water with an SAR between 10 and 18, and this water can present appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low leaching conditions, unless gypsum (calcium carbonate, which is common in most Montana soils) is present. This water may be used on coarse-textured or organic soils with good permeability.

High Sodium water is water with an SAR between 18-26. This water may produce harmful levels of exchangeable sodium in most soils and will require special soil management -good drainage, high leaching, organic matter additions, gypsum additions.

The following table helps categorize each of the water qualities:

Salinity Hazard				
EC (micromhos/cm)	Low	Medium	High	Very High
	100-250	250-750	750-2250	>2250
Sodium Hazard				
SAR	0-10	10-18	18-26	>26

MANAGEMENT OF SALINE AND SODIC SOILS GYPSUM, SULFUR, AND OTHER MYTHS—AGRONOMY NOTES NO. 116

http://scarab.msu.montana.edu/Agnotes/category_292.htm

Here is one of those notes which came about because one of the subscribers of Agronomy Notes -Steve Ostberg, up in the Fairfield area, sent me some information about a soil sample and wanted to know the diagnosis'. As I recall, the soil sample had a pH about 8.5 or so and the EC (electrical conductivity) was about 15 millimhos/cm. Generally, when a soil sample is submitted to a lab for testing, pH and conductivity, salinity, or conductance are standard background measures. In this case, the background measurements provided some very valuable information.

Based on the information Steve provided me, I diagnosed the soil as "saline-sodic", meaning that it had both a high salt content and it was saturated with respect to sodium. Sodium, calcium, and magnesium are the cations or positively charged molecules which generally predominate the surface of the soil. Productive, non-problem soils generally will have a pH between 6.5 and 8.2, an EC less than 1.0 millimhos/cm, and less than 15% sodium saturated. This soil sample had everything going wrong for it. So... Steve asked -can I add gypsum or sulfur to this soil to address the problem, i.e., will gypsum or sulfur correct the salinity-sodicity problem?

My response to Steve was as follows:

.....You asked about applying sulfur or gypsum to the soil which was tested as alkaline and saline (saline-sodic, as I recall). The answer: Adding either gypsum or sulfur to this soil won't likely do much good!

Gypsum is generally added to provide either a calcium source to displace the sodium or a sulfur source that will enhance acidification of the soil. (Gypsum is calcium sulfate, 22.5% calcium). Sulfur is added as a sulfur source -at high rates as an amendment and at low rates (10-40 pounds per acre) as a plant nutrient. When the soil is alkaline (or basic, pH greater than about 8.2), sulfur is sometimes added because sulfur serves to stimulate microbial action, the release of hydrogen ions, and the formation of sulfuric acid in the -thus causing a lowering of the pH and along with that an exchange of divalent cations (calcium, magnesium) for sodium.

For most soils in Montana east of the continental divide, the soil is already saturated with respect to calcium (carbonate). Hence, addition of more gypsum simply drives the solution reaction more to precipitation. Kind of like having a glass of water which is saturated with sugar and adding another teaspoon of sugar -sugar crystals form almost instantly on the bottom of the glass. When you add gypsum (a source of calcium) to a soil already saturated with respect to calcium, you are just elevating the concentration of calcium and hence pushing more precipitation of calcium carbonate. In contrast, when you add sulfur, there is a very good chance of acidification and release of hydrogen, which will cause formation of sulfuric acid and a displacement of the sodium -which will then be replaced by calcium. However, without adequate drainage and good water to move the sodium out of the soil, little reclamation is to be gained by adding sulfur.

Basic rule -when you are attempting to reclaim either a saline, sodic (sodium saturated) or saline-sodic soil, the first thing you need is good drainage -an outlet to send the sodium to when it is displaced. The next thing is a source of calcium (already in the soil), and exchange process, and finally, a source of water to flush the sodium from the system.

Bottom line -seldom will gypsum or sulfur make much difference in our soils, unless it is an isolated situation and drainage is available. You might get a short-term, surface response to sulfur -which could be because of a temporary lowering of the pH, the release of some sodium, and temporary improvement of soil structure, but this is generally only temporary. You are better off to attempt to increase organic matter levels by continuous cropping, minimize tillage, establish plant species, which will tolerate the salinity and remove some of the water. With time, a good reclamation program which is focused on plant selection, salt tolerance, and re-vegetation while cutting off the source of water is much more effective and sustainable than use of gypsum or sulfur.

Another interesting question: About nitrate concentrations in the soil. A gentleman called me the other day and asked what was the significance of soil nitrate concentrations of 10,000 parts per million. Yes! I couldn't believe it at first either. But, he explained that it was the result of some munitions processing in the past. He wanted to know if plants would grow there and what target soil concentration he should shot for. I looked in every book I had and the highest soil test nitrate concentrations I could find were in the range of 200 ppm. My recommendation: try to get the soil test level down to 400 ppm. Under the present conditions, nitrate-nitrogen is about 1% of the soil composition. And the likely problems -nitrate toxicity, excessive vegetative growth, and highly saline soil.

SALT PROBLEMS COMMON IN SOME SOILS OF MONTANA AGRONOMY NOTES NO. 137

http://scarab.msu.montana.edu/Agnotes/category_293.htm

Some time ago, I recall sending out a piece of information on Critical Soil Test Levels -addressing nutrient levels and some other parameters, such as organic matter, cation exchange capacity, electrical conductivity, and sodium adsorption ratio. With this note, I thought I might add a little more information about the issue of salinity and sodicity in Montana soils. Generally, there are several terms which are used interchangeably to describe salty soils -a practice which is technically incorrect. For instance, salinity, sodicity, alkalinity are all different conditions of the soil.

Salinity is a measure or index of the total amount of soluble salt in the soil or soil solution -all kinds of salts. Generally calcium, magnesium, and sodium salts; carbonates, sulfates. The standard measurement for salinity is the EC -electrical conductivity. Seldom (unless a very high water table or very inadequate leaching with poor quality water) will this be a problem on sandy or gravelly sites. Most common on silt loams, silty clay loams in areas of low rainfall (<14 inches per year). The following table provides a summary of the common conditions associated with saline soils.

Conductivity (EC), rating, and tolerant crops and plants:

?? -2.0 mmhos/cm; OK; all vegetables and crops

?? -4.0 mmhos/cm; slightly salty; beans, foxtail, barley, some clovers, radish, celery

?? 4.0 -8.0 mmhos/cm; moderate; cereals, alfalfa, clover, grass, most vegetables except radish, celery, green beans

?? 8.0 -16.0 mmhos/cm; strong; barley, beets, wheatgrass, wildrye, trefoil, fescue

?? 16.0 -+mmhos/cm; excess; very little -saltgrass

Sodicity refers to the degree to which the soil exchange capacity and sites are saturated or occupied with sodium ions (as compared to the more preferred calcium and magnesium ions). Sodium, a common component of you detergents and laundry soaps, is a dispersing agent. Hence, soils which are saturated with sodium tend to be very difficult to work with -little aggregation, sometimes consolidated and blocky, poorly drained. These are the soils we often refer to as "gumbo". The best indicator of sodicity in a soil is the SAR -the sodium adsorption ratio, which is a relative comparison of the amount of sodium compared to calcium and magnesium. Generally, soils with SAR greater than 15 are considered sodic. The most common way to deal with sodic soils is to add another cation, calcium or magnesium, to displace the sodium. But good drainage is essential. Alkalinity is the third term we often hear -technically it refers to the acidity of the soil. Soils which are basic (as compared to those which are acidic) are considered to be alkaline. The parameter most often used to determine the alkalinity of a soil is the pH. Soils with pH greater than about 8.7 are considered to be alkaline. Alkalinity is another one of those issues commonly associated with poorly drained sites. Hence, before any action can be taken to lower the pH, good drainage must be insured. Then, ample additions of organic matter, increased cropping intensity, or large amounts of sulfur can be used to lower the pH and create more acidic conditions.

So, the question becomes -can I have a soil with all of these conditions at the same time? And the answer is -YES - but not likely.

SUITABILITY OF WATER FOR LIVESTOCK
AGRONOMY NOTES NO. 146

http://scarab.msu.montana.edu/Agnotes/category_190.htm

Back in February, I received a call from Chet Hill, Roosevelt County Extension Agent in Culbertson. Apparently, a rancher in Roosevelt County was having some problems with livestock watering and wanted to know what was suitable water quality for livestock. A little digging provided some good information, which I thought I would share as summer gets closer. Most of my references are readily available and I have noted them here.

Some of the information here comes from a new bulletin of MSU Extension Service, EB 150, "Soil, Plant, and Water Analytical Laboratories for Montana Agriculture" (replacing Bulletin 1349), is now available through County Extension Offices or the MSU Publication Office at 406-994-2099 or by e-mail at ACXTB@MONTANA.EDU or VELTKAMP@MONTANA.EDU. One of the issues addressed in this bulletin offers the following guidelines about water quality suitable for livestock:

FROM TABLE 10
DRINKING WATER QUALITY STANDARDS FOR LIVESTOCK SUITABILITY.

Aluminum (Al)	5 ppm (milligrams/liter)
Arsenic (As)	0.2 ppm
Boron (B)	5 ppm
Cadium (Cd)	0.05 ppm
Chromium (Cr)	1 ppm
Cobalt (Co)	1 ppm
Copper (Cu)	0.5 ppm
Fluoride (F)	2 ppm
Lead (Pb)	0.05 ppm
Mercury (Hg)	0.1 ppm (Note: USDA lists 0.01 ppm)
Nitrate+Nitrite	100 ppm
Nitrite	10 ppm
Selenium (Se)	0.5 ppm (Note: USDA lists 0.05 ppm)
Vanadium (V)	0.1 ppm
Zinc (Zn)	24 ppm
Total Dissolved Solids	10,000 ppm
Magnesium + Sodium sulfates	5,000 ppm
Alkalinity (carbonate + bicarbonate)	2,000 ppm

A couple notes: ppm is an approximation of milligrams/liter, mg/l, which is the more commonly reported unit. The USDA, NRCS (formerly SCS), Montana Technical Note Environment No. 18, issued January 1982, cites the same standards as above, except where noted and references the Environmental Studies Board, Nat. Acad. Sci., Nat. Acad. Eng. Water Quality Criteria 1972.

With regard to saline water, the measure commonly referred to is the Total Dissolved Solids (TDS), which is approximated with the specific or electrical conductance, as measured in either micromohs/cm or deceseimens/meter. The criteria reported were as follows for saline water:

Specific conductance:

?? Less than 1,500 umhos/cm or TDS less than 1,000 mg/l—relatively low level of salinity; excellent for all classes of livestock.

?? 1,500-5,000 umhos/cm or TDS of 1,000—3,000 mg/l - satisfactory for all classes of livestock; may cause temporary, mild diarrhea in livestock not accustomed to the water.

?? 5,000-8,000 umhos/cm or TDS of 3,000-5,000 mg/l—satisfactory but may cause temporary diarrhea or be refused at first; poor quality for poultry.

?? 8,000-11,000 umhos/cm or TDS of 5,000-7,000 mg/l—can be used with reasonable safety for dairy and beef cattle, sheep, swine, and horses; avoid using with lactating animals.

?? 11,000-16,000 umhos/cm or TDS of 7,000-10,000 mg/l—unfit for poultry and swine; considerable risk for lactating livestock; should be avoided although older ruminants, horses may subsist on water of this quality under some circumstances.

?? 16,000 umhos/cm or TDS > 10,000 mg/l—unacceptable.

NOTE: conductance is sometimes reported as mmhos/cm, which is umhos/cm divided by 1000. To convert to umhos/cm, multiply mmhos/cm by 1000.

In Montana, the most commonly encountered problems are total dissolved solids, alkalinity, and nitrates. The basic rule in Montana is that livestock should not be watered with water which has a TDS > 10,000 mg/l and/or nitrate+nitrite > 100 mg/l.

Two other references which I found, and which state much the same as the above, are:

Soltanpour, P.N., and W. L. Raley. 1982. Evaluation of drinking water quality for livestock. Service In Action, Colorado State University Extension Service Quick Facts No. 4.908.

Jackson, G., B. Webendorfer, R. Hall, J. Crowley, and D. Keeney.1983. Nitrate, groundwater and livestock health. University of Wisconsin Cooperative Extension Fact Sheet G3217. (Contact Agricultural Bulletin Bldg, 1535 Observatory Drive., Madison, WI 53706. Phone 608-262-3346).

SOME GUIDELINES FOR IRRIGATING WITH SALINE WATER AGRONOMY NOTES NO. 155

http://scarab.msu.montana.edu/Agnotes/category_294.htm

The quality of water from Montana's rivers and streams generally decreases as the irrigation season progresses. Historic records indicate that sediment load is usually heaviest during the May and June snowmelt runoff periods and as the sediment load decreases and stream volumes decrease, the salt level of most rivers and streams increases. This is particularly true to the streams and rivers east of the Continental Divide. With that being the case, a few guidelines for irrigating with salty water might prove useful for irrigators—especially those using water from the Powder, Milk, Marias, Tiber, Musselshell, Tongue Rivers and secondary tributaries to the Missouri and Yellowstone Rivers.

Irrigating with saline (salty) water. The smaller rivers that supply most of the irrigation water for the eastern two-thirds of Montana are interesting—the saline and volume change dramatically during the year. Review of the historic water quality and flow records indicate several changes through the year. Knowledge of these changes may be of some value in attempting to "get the most" our of the available irrigation water.

?? Fill the profile as early as possible after the peak flood stage or as soon after harvest as possible, if you are harvesting forages (hay, alfalfa). The sediment and salinity levels tend to increase beginning early in the spring as runoff begins. Salinity level peaks and then starts to decrease as dilution takes over, while sediment continues to increase. During the high flow period salinity is low, but sediment is high. Sediment generally tends to start decreasing dramatically after the peak.

?? If at all possible, delay irrigation until after the peak flow period, as the flow level begins to drop. Salinity and sediment tend to be lower at this flow rate on the "down" or falling stage than the same stage on the "up" or rising level part of the cycle.

?? Some sediment in the water will help move the advancing wetting front across border-dike, graded border, basin, and furrow irrigated fine sandy loam soils.

Salinity (or salt load) is best determined by measuring the TDS (total dissolved solids) or EC (electrical conductivity). The TDS varies from as low as only a few hundred parts per million (or milligrams per liter), to as much as 2500 to 3000 parts per million (mg/l) during the lowest flow periods in some of the smaller streams of eastern Montana. The lowest TDS usually occurs when the river level has risen to its maximum and is then falling. When the river goes through rising and falling stages due to rain (especially thunderstorms), the TDS is usually lower at a given river level when the level is falling, rather than rising.

Irrigation strategies to reduce salt load. If possible, when irrigating in the spring and early in the irrigation season, fill the profile with water of low TDS/EC. The EC of the water will generally be between 0 and 9 mmhos/cm (equal to 9000 micromhos/cm). To convert this value to an approximate TDS (total dissolved solids), multiply the EC in mmhos/cm by 640. The result will be an approximate TDS in milligrams per liter. The soil will tend to concentrate salt during the irrigation season and thus have an EC greater than the irrigation water. In well-drained soils, the EC will be about the same all the way through the root zone, while on poorly drained soils, the EC will generally increase dramatically with depth. Young plants and seedlings are much more sensitive to EC of both the irrigation water and soil than established plants. Once the EC gets above about 2.4 mmhos/cm in the soil, plants will begin to show signs of stress—stress that looks just like drought.

Irrigation strategies to reduce salt injury to seedlings. On new plantings of alfalfa, grass, other legumes, small grains, corn, and sorghum, shorten the length of time or your sets early in the season, when plants are still small, and irrigate just a little more frequently. You'll pump just the same amount of water as before, but get a better stand, better early growth, and an increase of as much 25% in overall yield. In addition, the irrigation water will tend to have slightly less dissolved salt this time of the season. Use of saline water for irrigation. The following is a summary of an article by J. D. Rhoades, soil scientist with the U.S. Salinity Lab in Riverside, CA. The article first appeared in the October 1984 issue of California Agriculture. Saline water, or water which is generally classified as having too much dissolved salt for irrigation, can often be used successfully without hazardous long-term effects on the crops or soils. However, certain conditions need to be met:

?? The soil being irrigated must be well-drained

?? Salt tolerant crops (established alfalfa, barley, sorghum, sudan grass, sordan) should be the primary crops grown

?? Rotations should be planned to provide for a sequence of progressively more salt tolerant crops

?? Salts should be leached out of the soil in the spring or winter

?? As the salinity of either the irrigation water or soil solution increases (with prolonged crop water use and through the irrigation season), the volume of irrigation water applied should be progressively increased.

As Rhoades points out, adoption of new crop and water management strategies can further facilitate the use of saline water for irrigation. One strategy is to substitute more saline water (later in the irrigation season) for good quality water to irrigate certain crops in the rotation or well-drained soils. Whatever salt buildup that might occur in the soil from irrigating with salty water can be reduced in the following winter or spring from rainfall or irrigation with low-salinity irrigation water.

Soils do not usually become excessively saline from use of saline water in a single irrigation season. It may even take several irrigation seasons to affect the level of salt in the soil solution. The maximum soil salinity in the root zone that results from continuous irrigation with saline water does not occur when salty water is used only a fraction of the time.

For purposes of comparison, Colorado River irrigation water has a TDS of about 900 ppm, while the rivers of central and eastern Montana generally ranges from about 750-1,500 ppm during the irrigation season. Drainage water TDS will usually be 3,500 to 4,500 ppm.

SOIL SALINITY CROP AND FORAGE TOLERANCES AGRONOMY NOTES NO. 170

http://scarab.msu.montana.edu/Agnotes/category_295.htm

Occasionally, I will get a phone call from someone wanting to know about tolerance of various crops and plants to salinity. Generally, I try to preface my comments about crops with a few words about salinity. There are two sources of salts which appear in the soil: either from the soil itself or from irrigation or drainage water. In either case, the presence of saline conditions in the soil indicates 'inadequate' drainage, either due to very slow percolation rates, high water table, not enough water to cause leaching, or upward water movement. The essential requirement for mediating a salinity problem is three-fold: 1) improve the drainage such that the excess salts can be removed; 2) remove or reduce the source of the salinity, i.e., either shut off the water or reduce the amount of water being applied so that excess water is not present, and 3) add sufficient good quality water to leach the existing salts.

After this little speech, the individual calling usually asks "what crops can I grow in salt-affected soil?" The logical answer is 'salt-tolerant crops'. And, "those would be....?"

The following is a list of commonly grown crops, presented from most tolerant to least tolerant, with respect to salinity. The number beside each crop is the EC (electrical conductivity) of a saturated extract from the soil that the crop will 'tolerate' in the mature stage.

barley	8.0 mmhos/cm
sugar beets	7.7 mmhos/cm
wheat	6.0 mmhos/cm
safflower	5.3 mmhos/cm
soybeans	5.0 mmhos/cm
sorghum	4.0 mmhos/cm
corn	1.7 mmhos/cm
flax	1.7 mmhos/cm
field beans	1.0 mmhos/cm

For a complete listing and reference to salt tolerant crops, see the "Western Fertilizer Handbook", pages 30-35. Another one of those excellent reference books written for farmers.

The other question that comes up is something like this: "I have a saline seep which I have been trying to reclaim. What forage crops can I grow in the salt-affected area?" The answer to that question again depends on the soil conditions. However, the list of tolerant forages is pretty well defined. It looks like the following, from most tolerant to least tolerant:

tall wheat grass	7.5 mmhos/cm
wheat grass (fairway)	7.5 mmhos/cm
bermudagrass	6.9 mmhos/cm
hay barley	6.0 mmhos/cm
perennial ryegrass	5.6 mmhos/cm
birdsfoot trefoil	5.0 mmhos/cm
harding grass	4.6 mmhos/cm
tall fescue	3.9 mmhos/cm

Comment: seedlings are generally much more sensitive to salinity than established plants.

crested wheat grass	3.5 mmhos/cm
vetch	3.0 mmhos/cm
sudan grass	2.8 mmhos/cm
big trefoil	2.3 mmhos/cm
alfalfa	2.0 mmhos/cm
berseem clover	1.5 mmhos/cm
orchard grass	1.5 mmhos/cm
meadow foxtail	1.5 mmhos/cm
clover: alsike, ladino red, strawberry	1.5 mmhos/cm

As an approximation, you can assume that the yield of each of these forages and the previous crops will be reduced by 10-15% if the conductivity is increased 25%, 25-35% if the conductivity is increased 50%, and 50% or more if the conductivity is doubled.

So, the next time you suspect you have a salinity problem, collect a soil sample, send it to a lab and ask for the EC (electrical conductivity or conductance), the pH (an index of salinity), and the SAR—the sodium adsorption ratio. With that information and the list provided here, you should be able to decide what is the best cropping strategy for your situation.